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APPLICATIONS OF NICKEL

REPORT OF

THE SUBCOMMITTEE ON NICKEL

of the

COMMITTEE ON TECHNICAL ASPECTS OF CRITICAL AND STRATEGIC MATERIALS

MATERIALS ADVISORY BOARD
Division of Engineering - National Research Council

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Mr. Carl Rolle, Office of the Secretary of Defense, Installations & Logistics, Room 2B322, The Pentagon, Washington, D. C. 20310.

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Dr. Joseph R. Lane, Staff Metallurgist, National Research Council, National Academy of Sciences, 2101 Constitution Avenue, N. W., Washington, D. C. 20418.

NICKEL SUBCOMMITTEE

COMMITTEE ON TECHNICAL ASPECTS OF CRITICAL & STRATEGIC MATERIALS

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Mr. Glenn A. Fritzlen, Director, Engineering & Development, Stellite Division, Union Carbide Corporation, 1020 W. Park Avenue, Box 746, Kokomo, Indiana 46901.

Mr. A. M. Hall, Senior Technical Advisor, Battelle Memorial Institute, 505 King Avenue, Columbus, Ohio 43201.

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Mr. Ralph Vandeventer, Manager, Materials & Standards, Research Engineering Center, Ford Motor Company, 21500 Oakwood Blvd., Dearborn, Michigan 48124.

Liaison Representatives:

Mr. Harry Boertzel, AIR-52301, Head, Metals Branch, Naval Air Systems Command, Department of the Navy, Washington, D. C. 20360.

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Mr. Dedrick A. Woodard, Technical Advisor (Engineering), Market & Economics Division, General Services Administration, Washington, D. C. 20405.

Materials Advisory Board Staff:

Dr. Joseph R. Lane, Staff Metallurgist, National Research Council, National Academy of Sciences, 2101 Constitution Avenue, N. W., Washington, D. C. 20418.

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ABSTRACT

Production and consumption of nickel have nearly doubled in the last ten years. Nickel is used in many important military and civilian applications, incorporated in stainless steel and a wide variety of ferrous and non-ferrous alloys as well as in plating. Since production of the metal has tended to lag behind needs for many years, it seemed desirable to examine the trend in applications and the possibility of substituting more plentiful materials in the event of an emergency.

Stainless steels are the largest consumer of nickel, followed by superalloys, electroplating, and alloy steels. The function of nickel is not unique in practically any application. However, substitution will nearly inevitably result in a performance or an economic penalty. The report points out the substitution possibilities in a broad way. Any specific case, however, requires an engineering assessment which cannot be made in the abstract. The growth rates for the various applications of nickel are estimated.

I. INTRODUCTION

Nickel is an extremely important alloying element for both defense and non-defense applications. Its uses range from stainless steels (8 to 20% nickel in many grades), high temperature alloys for jet engines (25 to 78% nickel), and tough alloy steels (3 to 18% nickel), to electroplating, castings, non-ferrous alloys, and coinage. During the past several years, growth in the demand for nickel has exceeded supply. Due to the time required to develop underground mines and refineries, this shortage is expected to persist until at least 1971.

Government stockpile releases have been helpful in keeping strategic materials in production, but overseas export of our nickel-bearing scrap, an essential melting ingredient for many alloys, has tended to impede stainless steel and superalloy production.

In the sections to follow, current applications and projected growth of major nickel uses are described, together with potentials for substitution by other metals. Estimated production and consumption through 1973 are shown in Tables 1 and 2, followed by a concise statement regarding future usage trends by product class and by industrial market. These tables are followed by two graphs, Figures 1 and 2, depicting production and consumption trends for stainless steel.

The estimates of demand for various products containing nickel assure an economic situation similar to that existing during the writing of this report. It is expected that fighting in Asia will taper off, but that military demands will largely, if not fully, be replaced by civilian demands.

Table 1. Estimated Free World Primary Nickel Statistics, 1969-1973
(Figures in millions of pounds)

1. Productive Capability of Free World Producers (Nickel in all forms) reported by:

	Actual	Estimated					
	1967 (4)	1968	1969	1970	1971	1972	1973
USBM (1)	708 (2)	757	816	910	1,015	1,106	1,200
Producers (3)	736 (2)	800	885	995	1,100	1,200	1,280

2. Demand for Primary Nickel by Geographical Area: (1967 & 1968 figures are production, which fell short of demand)

	1967 (4)	1968	1969	1970	1971	1972	1973
USA	350	315 (5)	400	460	498	535	572
EEC	169	180	192	207	219	235	247
UK	74	82	90	96	101	110	119
Japan	111	120	130	136	141	150	159
All others	102	113	130	141	153	170	182
Total	806	820	942	1,040	1,112	1,200	1,279

Notes:

(1) USBM figures are taken from the report dated June 14, 1968 submitted to the Subcommittee by Mr. Harold W. Lynde, Jr., of BDSA.

(2) Not shown in the total is 40 million pounds made available in 1967 from the US Stockpile.

(3) Averaged estimates from data submitted by North American producers.

(4) For 1967, actual production and productive capability were identical.

(5) Drop in consumption due to working off of inventories acquired in anticipation of possible steel strike.

Table 2

Part 1: U.S. Future Usage Trends Applicable to Nickel by Product Class

Category	Estimated Usage 1966 (in millions of lbs.)	Usage Trend 1968-1973	Comments
Product Class			
Stainless Steel	130	increasing	continued upgrading of needs by customers to achieve non-corrosion
Alloy Steel	42	increasing	greatest growth is in maraging steels
Nickel-base, high temperature alloys	63	increasing	favorable heat resisting qualities create high demand for nickel
Electroplating	65	little change	demand appears related to automotive output
Castings	38	little change	nickel used in matured industrial applications
Non-Ferrous Alloys	19	increasing	new applications in cupro-nickel products, especially in desalination plants
Coinage	4	increasing	used to replace silver, but total free world needs are small (2%) compared to other product classes
Catalysts & Chemicals	6	little change	nickel used in matured industrial applications

Table 3

Part 2: U.S. Future Usage Trends Applicable to Nickel by Industrial Market

Category	Estimated Usage 1966 (in millions of lbs.)	Usage Trend 1968-1973	Comments
Industrial Market			
Motor Vehicles	53	little change	commensurate with rates of population and market growth
Aircraft	37	increasing	major new applications lie in engine area where control of high temperatures becomes of great importance
Marine Transportation	15	little change	demand may be affected considerably by military construction programs
Appliances, Utensils, & Service Machinery	39	increasing	growth dependent on population expansion & construction of service facilities, such as hospitals, schools, & public institutions
Electrical & Electronics Equipment	42	increasing	expansion of telecommunications systems together with military requirements will determine overall rate of growth
Agricultural, Mining, & Construction Equipment	12	increasing	construction equipment affected by public works programs; other markets anticipate rate of growth slightly higher than GNP
Metalworking Equipment	15	increasing	will anticipate the general industrial and GNP trends
Petroleum & Chemical Manufacturing Equipment	54	little change	long term increasing market due to upgrade of materials required by new processes

Table 3 (continued)

Part 2: U.S. Future Usage Trends Applicable to Nickel by Industrial Market (cont'd)

Category	Estimated Usage 1966 (in millions of lbs.)	Usage Trend 1968-1973	Comments
Process Industry Equipment	30	increasing	rate of increase is commensurate with growth factors applicable to this industrial market
Construction & Contractor's Products	22	increasing	overall rate of growth will follow individual rates in home building, public works, and commercial building
All Other (includes nickel bearing products not covered specifically above)	78	little change	most of these markets show little change because of increases and decreases working against one another; world coinage usage could increase but overall effect on total nickel market is small

NOTE: Figures for totals by Product Class and Industrial Market will not total equally because of rounding and lack of detailed record keeping.

Total Nickel Consumption and Nickel Consumed in Stainless Steel in the U.S.
1957-1967 with Projections 1968-1973

FIGURE 1.

Total Stainless Steel Ingot & Cr Ni Ingot Production in the United States
1957-1967 and Total Stainless Steel Shipments with Projections 1968-1973

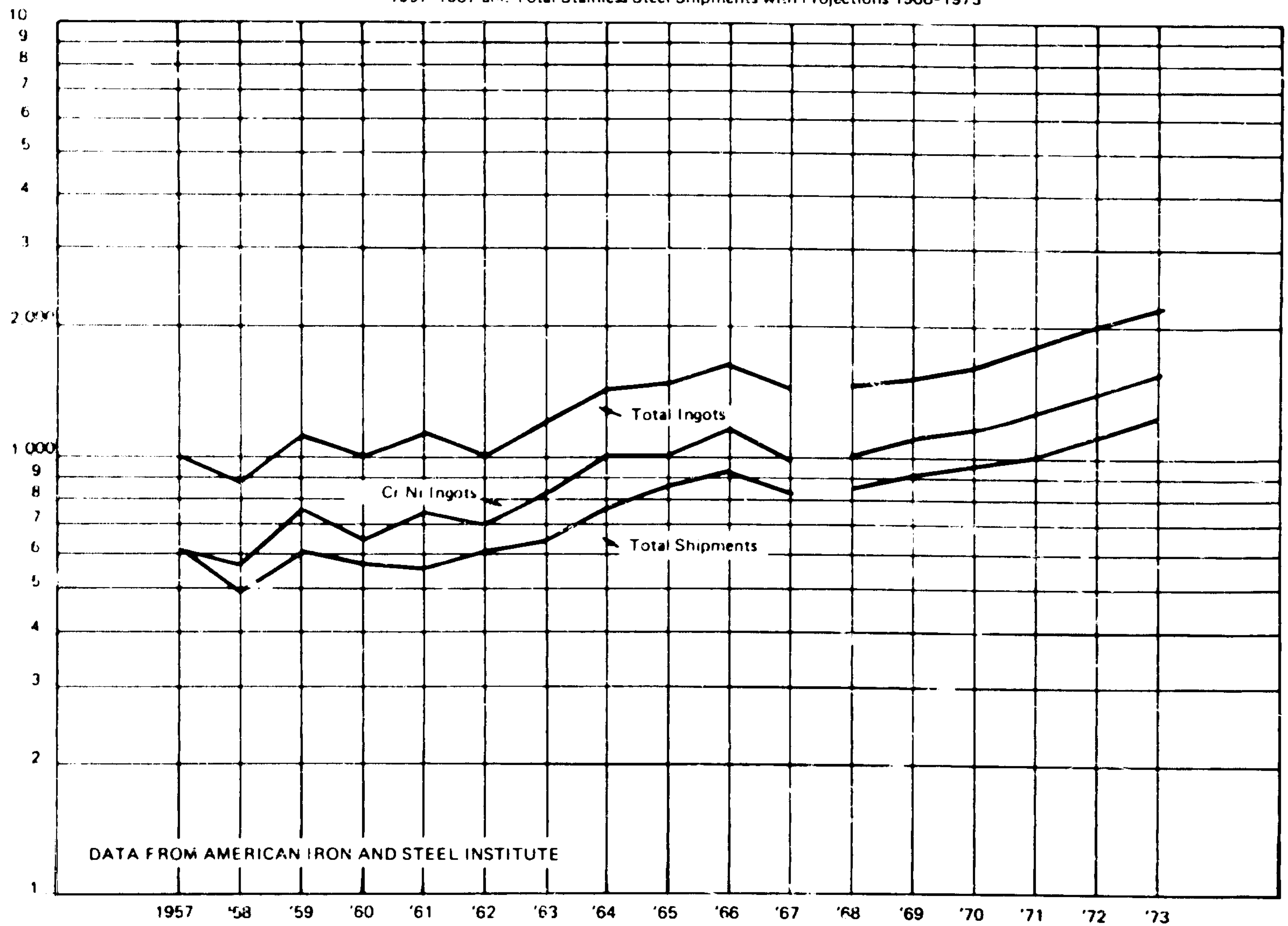

FIGURE 2.

II. NICKEL SUPPLY

A. World Nickel Resources

The world's nickel resources are in two types of ores, sulfide and laterite. Nickel occurs in the sulfide ores principally in the mineral pentlandite. The deposits are associated with ultramafic igneous rocks disseminated in massive bodies or in veins, stringers, and fissure fillings in the surrounding host rock. Most of the sulfide ores are mined underground.

The laterite ores have been formed by weathering of ultramafic rocks many of which have been metamorphosed to serpentine, facilitating the weathering process. In these deposits, nickel occurs principally in hydrous silicates, called garnierite, analagous in structure to serpentine. Most of the laterite ore bodies of the world are in tropic or subtropic climates. All are mined in open pits.

The sulfide deposits, principally those in the Sudbury district of Canada, have been the mainstay of the world's nickel supply. They average about 1.5% nickel associated with varying quantities of copper, iron, cobalt, and other valuable metals. Only the exceptional acidic laterite ores could be mined profitably until the last decade. Laterite ores containing less than 1.3% nickel and those high in magnesium could not be exploited profitably because of low recovery and high reagent cost.

At present the world is in a stage of transition from dependence on the sulfide ores for its nickel to increasing dependence on the laterites. The change is the result of both higher prices and improving technology. At present laterite ores containing as little as 0.6% nickel are of commercial interest if they are in the proper physical environment and in multimillion ton deposits. In practically any environment the large deposits are of definite commercial value if they contain 1% nickel or more.

Estimates of the world's reserves of nickel prepared in 1967 within the Bureau of Mines for use in its commodity-profile series are given in Table 4. The estimates indicate the general distribution and order of magnitude of the principal known deposits. They are believed to be ultraconservative.

TABLE 4

WORLD NICKEL RESERVES
(Million pounds contained nickel)

Country	Estimated reserves	Classification of deposits: Sulfide	Classification of deposits: Laterite	Grade
Australia	2,000	X	X	1.3-4.0
Brazil	1,200		X	2.0
Canada	20,000	X		1-3
Cuba	36,000		X	0.8-1.4
Dominican Repbulic	1,600		X	1.8
Greece	200		X	0.7-4.0
Guatemala	2,000		X	1.5
Indonesia	16,000		X	0.8-3.0
New Caledonia	33,000		X	1.0-5.0
Philippines	9,000		X	0.7-2.0
Puerto Rico	1,600		X	0.9
Rhodesia	1,400	X		9;1 (2/3 of reserves are byproduct)
South Africa, Rep. of	800	X		0.2
U.S.S.R.	20,000	X	X	0.4-4.0; 1.5-2.5
United States	1,800	X	X	[illegible]; 0.6-1.5
Venezuela	1,400		X	1.7
Other	3,400			
Total	151,400			

B. Nickel Production Forecast

The following sections briefly describe nickel production in the free world for the years 1964 through 1967, and make projections for the years 1968 through 1972. Also contained are a brief discussion of industry's ability to meet rapid increases in demand; a description of some Government activities in the present nickel shortage situation; and a description of materials in the national stockpile.

Major increases in nickel production capacity in the next five years are expected in at least three free world countries — Canada, New Caledonia, and Australia. Production also may increase at least 10,000,000 pounds annually in Rhodesia, and begin on a large scale in the Dominican Republic, Guatemala, and the Philippines.

Within ten years, production may increase significantly in such countries as South Africa, Indonesia, Greece, and Finland, and begin in Botswana, Colombia, British Solomon Islands Protectorate, and Venezuela.

The magnitude of the task ahead for producers is indicated by the fact that 7 of the 15 countries listed above do not presently mine nickel ores.

Of total historical world production of nickel of over 18,000,000,000 pounds, Canada has accounted for approximately 66% (51% in 1967); New Caledonia, 10% (14% in 1967); Communist countries, 17% (28% in 1967); and other countries, 7% (7% in 1967).

On a free world basis, Canada historically has accounted for approximately 80% of production, and New Caledonia, 12%. The trend in recent years has been for the Canadian share to decline gradually, and that of New Caledonia and other countries to increase. This trend will continue, as can be seen in the following summary tabulation, with figures given in thousands of pounds.

Year	Canada	New Caledonia	Australia	Other	Total
1967	500,000	136,000	4,000	68,000	708,000
1968	530,000	144,000	10,000	74,000	758,000
1969	560,000	160,000	16,000	80,000	816,000
1970	620,000	180,000	20,000	90,000	910,000
1971	680,000	200,000	40,000	94,000	1,014,000
1972	720,000	220,000	44,000	122,000	1,106,000

In 1971 or 1972, production could be augmented by initial output from such countries as Guatemala, Philippines, Colombia and Venezuela.

Aside from the increasing broadening of production geographically, there are two other important production trends: the growth in importance of laterite ores as a source of nickel, and the increasing importance of nickel oxide sinter and ferronickel as forms of primary nickel.

Sulfide Ores

Canadian ore production from nickel-copper sulfide ores has yielded, through advances in technology, not only nickel and copper, but as many as 13 other products (iron ore, sulfur, selenium, tellurium, gold, silver, cobalt, platinum, palladium, iridium, osmium, rhodium, and ruthenium). As a result, the nickel companies have been able to profitably mine ores with as little as 1 to 2% combined nickel and copper, down to depths of 7,000 feet.

Laterite Ores

The largest part of world reserves, however, is in laterite ores, where nickel has been concentrated to minable percentages by a weathering process. The fraction of a percent nickel in ultramafic igneous rocks is taken into solution in tropical weathering, then reprecipitated to produce nickel concentrations of 1-5% in material at less than 50 feet below the surface. Until the present, the only by-product has been cobalt, and it has rarely been recovered. Neither

pyrometallurgical nor hydrometallurgical processes have been entirely satisfactory, from a cost viewpoint, but intensive research in both areas over many years has reached the point where improved products can be produced at competitive costs. These technological advances are primarily responsible for the projected diversification in production to many additional countries.

In 1964, in the free world, production from laterites accounted for about 22% of total production; by 1967 it was 25%; and in 1972 it will be 26-30%. The percentage will increase to 35-40 ten years from now.

About one-half of primary nickel consumed is used in iron and steel products (constructional steels, stainless steels, etc.) in which ferronickel and nickel oxide sinter can be used. These materials are less expensive than nickel metal. In 1964, about 17% of free world nickel production was in ferronickel, and 13% in nickel oxide sinter; in 1967 about 22% was in ferronickel, and 11% in nickel oxide sinter. The potential market for these products together would probably be about 50% of total primary nickel consumption.

Comunist-Bloc Production

Although nickel production in the U.S.S.R. and Cuba accounts for a substantial percentage of world production, it is assumed that trade in primary nickel with these countries will not become a major factor in free world supply or demand. At any rate, this trade is not predictable. In immediately past years, Russian nickel has been marketed mainly in Europe and Japan, with the United States and other countries also receiving some metal. Cuban production has been sold to France and to China, with small amounts going elsewhere in the free world. France has also exported nickel to mainland China.

Free World Production

Free world production estimates for primary nickel for the period 1964-1972 are shown in Table 5. Projections are based on announced plans of the nickel

producers, but increases in production have been spread over more years than the companies originally indicated. The reason is primarily the absence of enough qualified labor. The values are based on ore removed from the ground, rather than refinery output which, in some cases like that of Japan, might be double-counted.

It takes several years to develop underground mines, and delays in bringing new mines into production, combined with the gradual decline in grade of ore mined, have caused producers such as Inco and Falconbridge much concern. Some of these problems were described in more detail at annual general meetings of Inco and Falconbridge stockholders.

In other areas where laterite ores are to be mined, the problems of negotiation with governments, unexpected droughts, the need to build housing, transportation facilities, power plants, and roads before undertaking mining have tended to stretch the lead time to a period of years, contrary to what one would expect for a strip mining operation. Financing also could be a problem for some firms.

The production outlook for each country is detailed below.

Canada

Canadian production will increase as The International Nickel Company of Canada Ltd., and Falconbridge Nickel Mines Ltd. expand operations.

Inco is continuing to develop its ten producing mines, and will bring nine or ten new mines into production during the period 1968 through 1972. The producing mines include nine in the Sudbury district, Ontario (Creighton, Frood-Stobie, Garson, Levack, Murray, Crean Hill, Clarabelle, Maclennan, and Totten), and one at Thompson, Manitoba (Thompson). Major development work continued at several of these mines.

The company is developing five new mines in the Sudbury district (Copper Cliff North, Coleman, Little Stobie, Kirkwood, and Copper Cliff South),

one in northwestern Ontario (Shebandowan), and three in the Thompson area (Birchtree, Soab, and Pipe). A tenth new mine is under consideration, the North Range, at Sudbury.

In addition to this work, the company is spending tens of millions of dollars on its ore processing and metallurgical plants, to handle the much larger quantities of ore which will be available. The increase in Inco's annual nickel production capacity should amount to 150,000,000 pounds by the end of 1971, bringing capacity to 600,000,000 pounds, including a small amount of purchased ores.

Falconbridge is bringing one large mine, the Strathcona, into production in 1968, and also a smaller one, Longvack South, to join six other producers in the Sudbury district (Falconbridge, East, Onaping, Hardy, Fecunis Lake, and North). Another property, the Lockerby, probably will not reach production before 1973. The additional production expected from these mine developments is 25,000,000 pounds, bringing cathode nickel production from the company's Norwegian refinery to 100,000,000 pounds. Another 9,000,000 pounds of nickel in an iron-nickel pellet form will be available when a recovery plant is completed in Ontario late in 1969.

Both Inco and Falconbridge process ores and concentrates of independent producers including Consolidated Canadian Faraday Ltd., Marbridge Mines Ltd., Lorraine Mining Company Ltd., Rottenstone Mining Ltd., and Kidd Copper Mines Ltd.

The third major Canadian nickel producer has no announced plans to expand production. Annual capacity of the Sherritt Gordon Mines Ltd. refinery is about 30,000,000 pounds; about 2/3 of the feed comes from its mine at Lynn Lake, Manitoba; the balance currently is primarily nickel matte from New Caledonia and sulfide ore concentrates from Australia. Another company, Giant Mascot Mines Ltd., exports its nickel-copper concentrates from operations in British Colombia to Japan.

Aside from the Inco and Falconbridge plans, other production increases for Canada cannot be pinpointed, but nickel exploration efforts continue at a high level, and additional unforeseen production could result within the projection period.

New Caledonia

New Caledonian production will increase primarily through expansion of capacity by Societé Le Nickel and through production by the new joint venture of SLN and Kaiser Aluminum and Chemical Corporation. Nickel ore exports are not expected to increase significantly over the projection period. As Australian nickel concentrates and metal become available to Japan, Japanese production of ferronickel from New Caledonia ores should level off.

New Caledonian production is estimated by type as follows, in pounds of contained nickel plus cobalt:

Year	SLN, in matte and ferronickel	Kaiser-SLN project	Recoverable, in ore exported
1968	84,000,000		60,000,000
1969	100,000,000		60,000,000
1970	110,000,000	10,000,000	60,000,000
1971	110,000,000	30,000,000	60,000,000
1972	130,000,000	30,000,000	60,000,000

The Kaiser-SLN joint venture will be in production in 1970 with part of its projected capacity of 33,000,000 pounds of nickel in ferronickel. The consortium of Inco (40% equity) and French firms and government agencies is not expected to achieve production in the forecast period. Another Canadian firm, The Patino Mining Corporation, has indicated it also is investigating the possibility of nickel mining in New Caledonia.

Other Countries

Australian production by Western Mining Corporation, which started in 1967, will reach 40,000,000 pounds annually by 1971 — 10,000,000 pounds in concentrates sold to Japan and Canada, and at least 30,000,000 pounds in nickel powder and briquets produced in a refinery to be constructed at Kwinana, Western Australia. Western Mining is expanding its high grade sulfide ore reserves at a remarkable rate, and in addition, has apparently discovered high grade oxidized ores.

There is intense exploration activity not only in Western Australia, but in other states, by literally dozens of firms, including most of the major nonferrous producers. Some additional production could be achieved in the forecast period, from new discoveries, since Western Mining was able to start nickel concentrate production within 17 months of the initial nickel discovery.

U.S. nickel production is expected to continue at about the same level as in the past, with almost all production in the form of ferronickel from the Hanna Nickel Smelting Company, Riddle, Oregon. The principal exploration effort domestically is centered in Minnesota, where several companies have exploration leases and permits, on private, State, and Federal lands. Inco, which has put down a shaft on its property recently announced generally discouraging exploration results. Anaconda, late in May 1968, announced a nickel discovery in the Stillwater igneous complex, Montana. Other recent exploration activity has been noted in Oregon, California, Alaska and Maine. Much of Puerto Rican reserves are on land covered with sugar cane. There are no known plans to mine these deposits.

Dominican Republic nickel resources will be developed by late 1971, according to an announcement by Falconbridge at its annual general meeting for stockholders, held in April 1968. The company plans to produce something over 50,000,000 pounds of nickel in ferronickel annually. The company currently is operating a pilot plant in the Dominican Republic.

Guatemalan resources are expected to be developed by Inco. The company, in August 1965, announced plans to develop these laterite resources. Negotiations with the Guatemalan government continue to the present, and a final production decision has not been made. Hanna Mining Company has a 20% interest in the project. Basic Incorporated, a Cleveland-based firm, also has explored nickel laterites in Guatemala.

Rhodesian nickel production is not known with certainty; since Unilateral Declaration of Independence, no official figures have been available. Estimates can be made by studying Japanese imports from Rhodesia. According to published reports, production at the Trojan mine will be as much as 6,000,000 pounds in 1968; production from the Madziwa mine beginning in 1969 will be about 6,000,000 pounds; and from the Empress, in 1972, about 12,000,000 pounds.

Botswana is an undeveloped country in southern Africa. Discovery of copper-nickel ores near Francistown was announced in February 1967 by the Roan Selection Trust Ltd. group. Efforts are in progress to finance a mining venture. The high expense and long lead time necessary in a country where there is no infrastructure (roads, communications, electric power) will probably preclude mining during the forecast period.

South African nickel production is a by-product of platinum-group metals production by Rustenburg Platinum Mines Ltd., at the Rustenburg and Union mines, and will increase as capacity is increased. In addition, nickel will be produced as a by-product of platinum mining by the Union Corporation, beginning in 1969.

Finland's nickel production by Outokumpu Oy from nickel-copper sulfide ores or Kotalahti is expected to remain relatively constant, with increased production resulting from a new mine to be developed at Nivala.

Greek ferronickel production at the Larymna smelter of Societé Miniere et Metallurgique de Larymna Larco S. A. currently is at the rate of

9,600,000 pounds per year. Production could eventually increase beyond this level, and refined nickel may be produced, rather than the ferronickel. The operation is a joint venture of Societé Le Nickel and Hellenic Steel-Chemical Producers and Fertilizers Company.

Brazil has two producers of ferronickel, Cia. Niquel do Brazil and Morro do Niquel S. A. Morro do Niquel, partly owned by Societé Le Nickel, is expected to increase capacity moderately.

Colombia could become a producer if the Hanna Mining Company, together with Standard Oil Company of California, reach agreement with the government on terms of mining nickel laterite in the Cerro Matosa area, Cordoba.

Venezuela in the past year has entered into agreement with Societé Le Nickel for that firm to investigate the Loma de Hierro nickel laterites in the States of Miranda and Aragua, and a report has been submitted. Future assignment of a mining concession would require legislative action. Production from this relatively isolated area is not predicted for the forecast period.

Indonesia, from which nickel laterite ores are currently exported to Japan through a consortium, Sulawesi Nickel Development Cooperative Company (Sunideco), has moved rapidly in the past 12 months to encourage development of large nickel resources. The International Nickel Company of Canada Ltd. has signed a contract under which the company may develop a large mining and processing operation at Malili, Sulawesi. The Malili area contains large reserves of low-grade ores, but no electric power, roads, cities, or communications. There is a large hydroelectric potential on the nearby Larona River. Development will necessarily be a long-range project; therefore, only current production rates from the Sunideco operation at Pomala are projected for the forecast period. Other areas of Indonesia also may eventually be mined for nickel.

Philippine efforts to develop a nickel industry based on extensive laterite occurrences have to the present been unsuccessful. Late in April 1968,

however, it was announced that Marinduque Mining and Industrial Corporation, a Philippine firm, had been chosen through a competitive procedure to develop the nickel resources of Nonoc Island, Surigao Mineral Reservation. Technical backing for the venture will be supplied by Sherritt Gordon. If a pilot plant project for treating these ores is successful, final agreement is reached with the Philippine government, and financing is arranged, the company intends to build a plant in the Philippines to produce 50,000,000 pounds per year of nickel metal, with initial output in 1971 or 1972. The schedule will be difficult to accomplish.

British Solomon Islands occurrences of nickel laterites on two islands are being explored by Inco. The company has obtained permission to mine and stockpile as much as 100,000,000 pounds of ore for possible export to Canada for metallurgical studies. No commercial production is assumed for the forecast period.

C. Flexibility of Supply

Nickel production capacity cannot be increased easily, quickly, or inexpensively. Major new projects require investments on the order of several tens of millions of dollars and three to six years' time before production is achieved, even after discovery and evaluation.

In the past, flexibility of supply was provided by large stocks of primary nickel held by producers. These stocks at times exceeded several month's needs; in 1958, Inco alone had accumulated stocks in excess of 100,000,000 pounds, and 1963, about 200,000,000 pounds. But in a rapidly expanding market like the one which developed between 1963 and 1966, use of producer stocks and reactivation of idle productive capacity combined, together with the effects of the strike at Inco, were not enough to prevent a shortage before new mines and production facilities could be brought to completion.

The Japanese and European steelmakers have been purchasing U. S. scrap at over five times the prior rate and at over three times the going value of

contained nickel. In the metals industry, it is axiomatic that one cannot long survive if return scrap is depleted (in this case overseas) and already extremely short prime alloy must be substituted. This problem has been reviewed with Government officials by industrial committees.

D. Recent Government Activities

Government activities affecting nickel during the past three years have centered upon foreign trade, stockpile activities, and defense requirements.

Foreign Trade

Import duties on ferronickel, unwrought nickel, and nickel powder were suspended September 28, 1965, through June 30, 1967, under Public Law 89-204, and from July 1, 1967, through September 30, 1967, by Public Law 90-48. As a result of Kennedy Round GATT negotiations, and certain discretionary powers available to the President, the tariff on these three nickel items was eliminated effective January 1, 1968. Other primary nickel materials, including nickel oxide and nickel oxide sinter, are not dutiable.

The suspension of duty on nickel waste and scrap was continued from July 1, 1965, through June 30, 1967, by Public Law 89-61, and from July 1, 1967, through June 30, 1969, by Public Law 90-45.

Exports of nickel alloy and nickel stainless steel scrap increased greatly from 1965 to mid-1967. A further rapid growth in export license applications prompted the Bureau of International Trade, U.S. Department of Commerce, to impose validated export licensing on all nickel-bearing materials not already covered, to all destinations except Canada. In addition, on June 10, 1967, the agency withheld issuance of new export licenses on nickel alloy and nickel stainless steel scrap in order to study the unusual export demand, and the resulting inflationary effect on domestic prices for scrap. On July 10, licensing was resumed, with special provisions to maintain close surveillance of these exports.

To date, no quantitative controls on nickel exports have been imposed. Since early 1968, export and domestic scrap prices, and quantities of scrap exported have been declining, although still ahead of previous years.

E. Stockpile Actitivies

At the end of 1964, Government stockpiles contained approximately 434,000,000 pounds of nickel, 334,000,000 pounds of which was excess to the 100,000,000 pound objective. This material was contained in the Defense Production Act (DPA) inventory and the National Stockpile. Late in 1964, General Services Administration (GSA) undertook a program to dispose of about 104,000,000 pounds of nickel in the DPA inventory; this disposal was completed in 1966. Public Law 89-323, November 5, 1965, authorized disposal of 200,000,000 pounds of excess nickel in the National stockpile; this material was committed by mid-1966. Of this total, 50,000,000 pounds went to the Bureau of the Mint, for coinage. Public Law 89-740, November 9, 1966, authorized sale of the remaining 24,500,000-pound surplus in the National stockpile; except for a small amount reserved for hardship cases, the balance was used in defense-rated orders.

In January 1967, the Office of Emergency Planning announced a revised nickel stockpile objective for conventional wars of 40,000,000 pounds. At about the same time, objectives for nuclear wars were announced, the nickel total being 35,000,000 pounds. The larger of the two objectives determined the size of the inventory to be held. On April 20, 1967, the House of Representatives passed H. R. 5786, a bill authorizing disposal of the surplus nickel. The National Stockpile Subcommittee of the Committee on Armed Services of the Senate, after a public hearing May 15, 1967, agreed not to forward the bill. The situation has not changed in the past year.

Defense Requirements

In July 1966, the Ontario mining and refining operations of Inco, the principal supplier of nickel to the United States, were struck. Because of the

impact of greatly increased defense requirements, the Business and Defense Services Administration (BDSA), under authority of the Defense Production Act of 1950, as amended, ordered the three U.S. suppliers of primary nickel to set aside a percentage of their nickel deliveries for use in materials for defense, atomic energy, and space programs (defense rated). Although the percentage requirement and the base period for computing the individual company requirements have varied, the setasides have continued each month since August 1966. The three companies affected include: The International Nickel Company, Inc., New York City; Hanna Mining Company, Cleveland; and N. C. Trading Company, New York City (affiliated with Societé Le Nickel).

The National Stockpile

According to General Services Administration, only three nickel materials remain in the national stockpile -- cathode nickel, nickel briquets, and Nicaro nickel oxide powder. The inventory is divided as shown below, with approximate figures in pounds.

Material	Stockpile	Excess
Cathode nickel		
25 inches by 36 inches	1,600,000	2,178,000
12 inches by 25-29 inches	28,400,000	27,142,000
4 inches by 4 inches	--	20,000
Briquets	10,000,000	15,998,000
Nickel oxide powder	--	16,744,000

The existing GSA National Stockpile Specification for Nickel (PR-36-R1) is tabulated below.

		Percent by Weight					
		Electrolytic Nickel	Nickel Ingots	Nickel Briquets	Nickel Shots	Nickel Oxide	Sintered Nickel Oxide
Ni + Co min.		99.50	98.50	99.50	98.90	76.50	76.50 1/
Co	max.	1.00	1.00	1.00	1.00	1.00	1.10
Fe	max.	0.25	0.90	0.25	0.60	0.50	3.00
S	max.	0.02	0.07	0.02	0.05	0.05	0.08
C	max.	0.10	0.30	0.10	0.25	0.10	0.10
Cu	max.	--	--	--	--	0.30	0.30

1/ When the nickel plus cobalt content of sintered nickel oxide exceeds the minimum requirement the cobalt, iron, sulfur, carbon, and copper may increase proportionately.

The following composition limits are suggested:

		Electrolytic Nickel	Nickel Briquets	75% Nickel Oxide Sintered	90% Nickel Oxide Sintered
Ni + Co min.		99.50	99.50	75.00	90.00
Co	max.	0.15	0.15	0.90	0.90
Fe	max.	.02	.02	1.00	1.00
S	max.	.02	.02	.04	.04
C	max.	.05	.05	.10	.10
Cu	max.	--	--	.75	.30

Comparison of the above compositions with the existing specification will show that the major changes would be in the maximum allowable cobalt for the electrolytic and briquet forms; these are thought necessary because of increasing demand for nuclear applications for corrosion resisting steels with

0.05 maximum cobalt. (There have been orders with even more restrictive limits of .01 maximum cobalt and these are met by resorting to the use of carbonyl nickel.)

There are two other forms of nickel additions which are used but are not shown in P-36-R1. These might be considered for listing therein: 50% nickel pig and 25% pig, balance, essentially iron.

It is also suggested that packaging in drums be encouraged and use of bags discouraged. All nickel that is of a shape and/or form such that it cannot be physically prepared by banding on pallets should be packed in drums or cans with a consistent amount of contained nickel in each drum or can. Identification should be marked on the side walls of cans as well as the lids in that when the can is opened the identification cannot be lost if the lids are discarded or mixed. Current capabilities in materials handling such as palletizing should also be considered.

Table 5. Estimated Free World Nickel Production (Recoverable Nickel)
(Thousand Pounds)

Country	1964	1965	1966	1967	1968	1969	1970	1971	1972
United States-------------	24,370	27,020	26,474	29,230	30,000	30,000	30,000	30,000	30,000
Canada--------------------	456,992	518,364	447,220	500,360	530,000	560,000	620,000	680,000	720,000
Latin America:									
Brazil------------------	2,200	2,456	3,052	3,000	3,000	4,000	4,800	4,800	4,800
Colombia----------------	--	--	--	--	--	--	--	--	--
Dominican Republic------	100	100	100	400	400	400	400	400	20,000
Guatemala---------------	--	--	--	--	--	--	--	--	--
Venezuela---------------	--	--	--	--	--	--	--	--	--
Europe:									
Finland-----------------	6,812	6,482	6,952	7,000	7,000	7,000	9,000	12,000	12,000
Greece------------------	--	--	330	6,000	8,000	8,000	8,800	8,800	8,800
Africa:									
Botswana----------------	--	--	--	--	--	--	--	--	2,000
Morocco-----------------	740	794	860	800	800	800	800	800	800
Rhodesia----------------	346	1,540	1,540	1,540	4,000	8,000	12,000	12,000	16,000
South Africa, Rep. of---	8,000	10,000	11,400	12,000	13,000	15,000	17,000	19,000	19,000
Asia and the Pacific:									
Australia---------------	--	--	--	4,660	10,000	16,000	20,000	40,000	45,000
British Solomon Is. Prot.	--	--	--	--	--	--	--	--	--
Burma-------------------	156	110	696	200	200	200	200	200	200
Indonesia---------------	1,902	3,128	4,660	6,770	7,000	7,000	7,000	7,000	7,000
New Caledonia-----------	104,470	106,108	122,966	135,710	144,000	160,000	180,000	200,000	220,000
Philippines-------------	--	--	--	--	--	--	--	--	--
South Korea-------------	32	2	--	--	--	--	--	--	--
Total-----------------	606,120	676,104	626,250	707,670	757,400	816,400	910,000	1,014,600	1,105,600

III. USAGE BY METAL TYPES

A. Trends in Usage of Nickel in Stainless Steel

Growing Awareness of Corrosion Costs

Reduction of corrosion . dustry could save several billions of dollars per year. Corrosion is a severe problem in the chemical, oil, marine and automotive industries to name just a few. Corrosion of buried distribution pipe for gas, water and drainage leads to costly replacement and repair. Many engineers have only a limited knowledge of corrosion science but more emphasis is now being given to the subject both at school, industrial and federal levels. This will lead to an accelerated use of corrosion resistant materials including nickel bearing stainless steels. Thus, the general awareness of corrosion costs and an increasing knowledge of corrosion science will change the historic growth curves for many markets. Much stainless is used, however, not because of corrosion resistance, but because of its attractive appearance, due to its intrinsic mechanical properties, or because periodic repainting is not required.

Effect of Population Growth and Improvement in Living Standards

It took until about the year 1850 for the world population to reach the one billion level. By 1925, man reached the two billion level and attained the three billion level in another 35 years. Based on this trend, we will reach four billion by 1980 and five billion by 1990. Thus, although the projection of nickel usage is limited in this study to an extension through 1973, we must consider the effects of the world population explosion and the planning which must be done to meet human demands.

The increase in population will have a tremendous effect on the demand for stainless in all markets, but because of changing technology the greatest effect will probably be in those markets associated with food and agricultural products.

Of particular interest is the demand for agricultural products. Studies have indicated that putting more land to cultivation is not the answer. Thus, more emphasis will be placed on increasing productivity per unit of land. To accomplish this requires adequate water, improved mechanization, pest control and fertilizer. We are already witnessing an increased demand for stainless to handle weed killers, pesticides and fertilizers. This rather new demand will accelerate at a very fast rate in relation to other markets.

Market Projections

Nickel projections by major market areas involve a lot of judgment. Tables 6, 7 and 8 show total stainless steel shipments, shipments for the top 15 markets and shipments comparing 1967 with 1957. This information is most helpful in analyzing major market projections. It is particularly interesting to note that the top 15 markets account for 74% of the total (See Table 6). The rate of growth in these markets is shown in Table 8. To assess what future changes may occur it is proper to examine major markets on the basis of changing application and technical requirements and to reflect on what may happen in other markets.

Construction industry. The construction industry has taken over from automotive as the largest single market for stainless. The rate of growth has even been greater than that predicted ten years ago. This can be attributed to three factors: (1) A change in architectural concepts; (2) Assistance by the steel companies to product manufacturers in design assistance and promotion of stainless steel items; (3) Proof in the market place of the advantage of stainless steel over competitive products in the area of beauty, strength, workability, corrosion resistance and ease of maintenance. This market is expected to grow at the annual rate of about 6%. However, because of even greater acceptance of stainless contractor products and because of new product developments, we may see this market grow at an even more rapid rate. For example, the use of stainless steel for flashing, fascia, roofing or other drainage products is just beginning to find major application in the market. The application is expected to grow to 24, 000,000 pounds per year within the next ten years.

TABLE 6

TOTAL STAINLESS STEEL SHIPMENTS
Direct Mill, Service Center and Imports (Thousand Pounds)

AISI Market Class	1967	Cumulative %
1. Construction, Including Maintenance, and Contractor's Products	250,250	13.3
2. Automotive	245,132	26.4
3. Other Domestic and Commercial Equipment	159,350	34.9
4. General Industrial Equipment	128,432	41.7
5. Appliances, Utensils and Cutlery	119,612	48.1
6. Aircraft	114,516	54.2
7. Bolts, Nuts, Rivets and Screws	67,626	57.8
8. Electrical Machinery and Equipment	61,170	61.1
9. Metal Working Equipment (Including Machine Tools)	49,268	63.7
10. Food Processing Equipment	49,254	66.3
11. Other Special Industrial Equipment	42,462	68.6
12. Chemical Industry Equipment	41,724	70.8
13. Shipbuilding and Marine	25,028	72.1
14. Textile Equipment	18,666	73.1
15. Pulp and Paper Equipment	16,362	74.0
TOTAL	1,388,852	----
ALL OTHER	486,228	26.0
GRAND TOTAL	1,875,080	100.0

Data from Industry Sources.

TABLE 7

TOTAL STAINLESS STEEL SHIPMENTS
Direct Mill, Service Center and Imports (Thousand Pounds)
Top 15 Markets

	SIC Code	Market Class	1967	Cumulative, %
1.	3461	Metal Stampings	170,878	9.1
2.	3429	Hardware, n.e.c.*	94,434	14.1
3.	3717	Motor Vehicles and Parts	74,290	18.1
4.	3452	Bolts, Nuts, Rivets and Washers	67,626	21.7
5.	3443	Boiler Shop Products	65,648	25.2
6.	3722	Aircraft Engines and Parts	60,962	28.5
7.	1900	Ordnance and Accessories	49,334	31.1
8.	3729	Aircraft Equipment, n.e.c.*	40,980	33.3
9.	3444	Sheet Metal Work	40,234	35.4
10.	3391	Iron and Steel Forgings	39,194	37.5
11.	3494	Valves and Pipe Fittings	35,774	39.4
12.	3551	Food Products Machinery	31,302	41.1
13.	3599	Miscellaneous Machinery	31,108	42.8
14.	3559	Special Industry Machines, n.e.c.*	29,564	44.4
15.	3623	Welding Apparatus	29,210	46.0
		TOTAL	860,538	----
		ALL OTHER	1,014,602	54.0
		GRAND TOTAL	1,875,140	100.0

*n.e.c. - Not Elsewhere Classified

Data from Industry Sources.

TABLE 8

TOTAL STAINLESS STEEL SHIPMENTS
Direct Mill, Service Center and Imports (Thousand Pounds)
Comparison of 1967 with 1957

	AISI Market Class	1957	1967	Change %
1.	Construction, Including Maintenance, and Contractors' Products	103,932	250,250	140.8
2.	Automotive	221,696	245,132	10.6
3.	Other Domestic and Commercial Equipment	84,410	159,350	88.8
4.	General Industrial Equipment	72,198	128,432	77.9
5.	Appliance, Utensils and Cutlery	77,248	119,612	54.8
6.	Aircraft	85,248	114,516	34.3
7.	Bolts, Nuts, Rivets and Screws	45,950	67,626	47.2
8.	Electrical Machinery and Equipment	36,942	61,170	65.6
9.	Metal Working Equipment (Including Machine Tools)	45,276	49,268	8.8
10.	Food Processing Equipment	40,108	49,254	22.8
11.	Other Special Industrial Equipment	42,486	42,462	.1
12.	Chemical Industry Equipment	26,174	41,724	59.4
13.	Shipbuilding and Marine	16,686	25,028	50.0
14.	Textile Equipment	14,678	18,666	27.2
15.	Pulp and Paper Equipment	7,782	16,362	110.3
	TOTAL	920,814	1,388,852	50.8
	ALL OTHER	263,336	486,228	84.6
	GRAND TOTAL	1,184,150	1,875,080	58.4

Data from Industry Sources.

Other new products and concepts cannot help but influence the growth of this market. On a technical basis the major factor that can bring about accelerated growth is color. Some colored stainless products are now available but a number of technical, production and economic problems remain. Thus the work being done on colored stainless could result in a tremendous increase in stainless usage in the construction industry. Lower nickel stainless grades (200 or 400 Series), aluminum, and carbon steel are possible alternates.

Automotive industry (including trucks, trailers and containers). Stainless shipments to the automotive industry are discussed in another section of the report.

Approximately 75,000 vans are built per year. Approximately 6% of current sales is stainless at an average of about 1,500 pounds per van. A technical change (redesign to permit the use of riveted construction) combined with greater acceptance on the part of the truckers will see this market grow to about 10% by 1973. Because of the growth of the riveted concept the average number of pounds per trailer may be somewhat lower by 1973. About 7,000,000 pounds is consumed today but by 1973 it is estimated that about 10,000,000 pounds will be required.

Approximately 25,000 shipping containers are now built per year. Projections are that 50,000 containers will be built per year in 1973. About 2% of the total container market at the present time is for containers that carry liquids. To permit versatile usage, Type 304 is used as the material of construction. Approximately 5,000 pounds of Type 304 are used in each tank. The liquid container market is only in its infancy. It is reasonable to predict that 5% of the total shipping container market will be for transporting liquids by the year 1973. Thus, 2,500,000 pounds of stainless is consumed today, but 12,500,000 pounds will be required by 1973. Aluminum or glass-lined tanks are possible alternates.

Other domestic and commercial equipment. This market class includes restaurants, hotel and galley cooking equipment, domestic furniture, office

furniture, dishwashers and sporting goods. The largest share of this market is in the area of restaurant equipment. This market will grow basically with population and demand for commercial construction. The only technical aspect that might affect this market is a change in the method of feeding. Centralized kitchens could involve the use of containers for handling which for sanitary reasons would require stainless. The development of infra-red and microwave ovens for rapid feeding of large numbers of people will lead to an increased use of stainless. This is a new concept in feeding that could grow in a similar manner to the vending machine industry. If institutions such as public schools accept this method of mass feeding, the market could grow by 1973 by an additional 10,000,000 pounds per year over and above historic projections.

Obvious substitutes are straight chromium steels, nickel-plated carbon steel, aluminum, porcelain enameled steel, glass, and tinned cast iron.

General industrial equipment. This market includes boilers and associated equipment, industrial pumps, industrial valves and fittings. If steam generating plants are considered a part of this market, then a more rapid rate of growth can be expected for this section of the market versus the remainder.

Stainless steel condenser tubing took about 50% of the total condenser footage ordered in 1967. Probably the most popular condenser tubing for severe conditions is cupronickel, with a much higher nickel content than stainless steel (10-30%). However, Admiralty metal, and aluminum bronze are nickel-free alternates frequently employed.

The power industry is projecting a size which doubles in ten years. In addition to this, nuclear power will take an ever increasing proportion of the market. Nuclear power is estimated to be growing at an 8% annual rate. Since the requirements for power plants through 1973 are already known, it is not difficult to project nickel requirements. About 275 pounds of nickel are required per MW for a conventional plant; 800 pounds per MW for a nuclear plant based on pressurized water concept; and 400 pounds per MW based on boiling water concept.

About 90% of these requirements are stainless steel in the conventional and boiling water reactor and approximately 65% are stainless in the pressurized water design with the remainder being Alloy 600. Fast breeder reactors (after 1975) would require heat exchanger tubing of an alloy such as Incoloy 800, calling for an additional 125 pounds of nickel per MW.

There are literally millions of feet of gas service lines in the United States. These are the lines that lead from the main to the home. There is work being done to evaluate Type 316 for this market. By 1973 this market may witness the beginning of its growth. Only small quantities of stainless will be used by then but the next decade will see this application become a major growth market. Plastic-covered aluminum may be a formidable competitor for this purpose.

Appliances, utensils and cutlery. This market includes utensils, hollow-ware, flatware, cutlery, small and major appliances. The growth of this market is related to the growth in population. There are no major technical aspects which would appear to influence the growth of this market other than finishing techniques.

Finishing costs continue to be a major obstacle to a more rapid growth of this market. The use of temporary plastic coatings is beginning to influence some final finishing costs. In addition, glass bead peening for finishing welds or damaged areas is favorably influencing final costs. These factors are gaining popularity among fabricators and may lead to more growth than might be predicted purely on the basis of population growth. Alternates are those listed under "Other Domestic and Commercial Equipment."

Aircraft. This topic is handled in a separate chapter.

Bolts, rivets, nuts, screws and accessories. Since the fastener industry is related to requirements of automotive, aircraft and appliance industries, its growth rate is basically dependent on these markets. Carbon and alloy steel, titanium and aluminum are alternates.

Electrical machinery and equipment. This market includes power generating and distribution equipment, electrical apparatus and communication equipment. The power industry projects a growth that doubles every decade. Technical changes in power generating, distribution equipment and communication equipment are continuous and become more sophisticated every year. A large percentage of stainless in this market is the 400 series. The substitution of certain nickel bearing maraging steels for 400 series turbine buckets is a possibility but will probably not occur until after 1973. Nuclear power and surface condensers are discussed under "General Industrial Equipment."

The present trend toward burial of distribution equipment and associated items could lead to a substantial increase in nickel bearing stainless requirements. Although technical work is being done in this area now, the major impact on the market will probably not occur until after 1973. Possibly 2,000,000 pounds of Type 300 series alloys will find application in this new market by 1973 because of these burial programs. Lead- and plastic-covered cables are technical alternates; overhead distribution lines are a functional substitute.

Metal working equipment This market includes welding rods, forging, stamping and milling equipment, special devices and tools, jigs and fixtures, and rolling mill machinery. There are no major technical changes which appear to have a significant influence on the growth of this market by 1973.

Food processing equipment . This market includes packaging, canning, dairy, beverage, baking and related equipment. Because of living standard changes this market is expected to grow at an accelerated rate in the years ahead. Stainless is the preferred material for food handling equipment. There is also a trend toward cryogenic methods of food processing. This will add to the growing use of stainless in the market.

Other special industrial equipment. This industry includes oil and petroleum processing equipment, commercial laundry and dry cleaning equipment, printing machinery and foundry equipment. The petroleum industry deserves special consideration.

Increased amounts of sulfur in crude oil, hydrotreating processes, large single stream processing, and the need for greater reliability to avoid plant shutdown because of the failure of single components have all led to an increasing use of stainless steels in the petroleum industry. The amount of Alloy 800, for hydrocracking applications, will remain about the same as today; however, because of hydrotreating the use of HK40 (cast Type 310) for steam methane units will almost double by 1975. Work is also being done in the oil industry on tar sands, shale and coal. Processes for tar sands, shale or coal all operate in the area of approximately 1700°F, therefore, if there is a technical breakthrough in the economics of hydrogen production, we will see an increased use of high strength stainless or some modified new high temperature stainless alloy. One example of this is an oil shale plant which is now in the design stage. This plant will require 400,000 pounds of nickel in stainless, or high temperature alloys. About one-half of this is in HK40 furnace tubes.

In engineered plants of this kind, a careful balance is struck between first cost and frequency of replacement. While some possibility exists of replacing nickel with other elements, for the most part substitution with lower-nickel compositions would shorten plant life and lower operating efficiency.

Chemical industry equipment. This industry includes chemical manufacturing industries' machinery and equipment, plastic working machinery and rubber working machinery. Included in this category is the equipment for manufacture of such products as weed killers, pesticides and fertilizers, containers to store them in central distribution centers, and smaller containers used in the process of application to the soil. This market is growing at a very fast rate. Some weed killers, pesticides and fertilizers will require nickel-bearing stainless steel; others will be able to use straight chromium grades such as 409 or other competitive materials. The important factor, however, is that this is a large growth market which today is only in its infancy. Tonnage projections are anyone's guess but it is not inconceivable to project an additional market of 10 million

pounds per year of stainless for containers to handle weed killers, pesticides and fertilizers by 1973, and 40 million pounds per year by 1980 (equivalent to about 1 million and 4 million pounds nickel, respectively).

The treatment of water and wastes can be considered in a broad sense in the category of the chemical industry. The changing technology in waste and potable water treating plant is leading to an increased usage of stainless, principally Type 304 and Type 316. The following table shows this increase in pounds of stainless steel (containing 10-12% Ni) required.

	1967	1980
Industrial	4,000,000 lb	12,000,000 lb
Sewage	4,400,000 lb	18,000,000 lb
Potable	6,000,000 lb	11,000,000 lb

Note: This table includes applications that also belong in other industry classifications.

Shipbuilding and marine. The use of 304 and 316 grades for multi-purpose liquid cargo-carrying barges, and containers in vessels to transport products such as orange juice and wine comprise the major expanding marine market.

There is a trend toward the use of stainless alloys such as Almar 362 and 17-4PH to replace other alloys (such as very low-nickel carbon steel or high-nickel monel) in the boat shaft market. New developments such as Type 216 which appears to have superior pit corrosion resistance much needed in this industry, may lead to greater utilization of stainless.

Textile equipment. This market consists of fiber-to-fabric machinery. There are no major technical changes which appear to have a significant influence on the growth of this market by 1973.

Pulp and paper equipment. This market consists of pulp and paper machinery for manufacturing paper and paper board, box making and related equipment.

During the last few years, pulp manufacturing has undergone revolutionary changes in technology and processing. Among these are the introduction of continuous digesting, new methods of sulfite pulping, and chemical recovery to eliminate air and water pollution. This has resulted in an annual increase in stainless consumption from about 15,000 tons to an estimated 22,000 tons.

Railroad industry — hopper and tank cars. The year 1966 established a record for money spent for new railroad cars. During that year, 24,439 open hopper cars, 20,636 covered hopper cars and 5,675 tank cars were built. In 1967, the figures were 20,944, 17,311 and 8,782, respectively.

Covered hopper cars are a growth market for stainless. By the very nature of its construction, a covered hopper car emphasizes the need for protection of the contents. In some cases this protection from the elements is augmented by linings or coatings to prevent or minimize contamination of the lading by the car itself. Many commodities in the chemical, pharmaceutical, plastic or drug industries, to mention a few, require contamination protection. Technical evaluations are being made to develop a stainless covered hopper car that would afford maximum protection to a wide variety of products and yet be competitively priced. This can now be done because of the development of AM 363 which is a low cost, high strength stainless alloy with good fatigue properties. Progress is steady and it is anticipated that by 1973 the production rate for stainless hopper cars will be approximately 500 per year or approximately 5,000 tons per year of AM 363 (equivalent to 400,000 pounds of Ni).

Another growth area is the use of stainless steel in tank cars. This is not a new concept but due to regulations governing the minimum thickness of materials used, a stainless car is essentially "over-designed," quite costly and, therefore, has had only limited application. New designs that minimize the amount of stainless used would lower the cost of cars and greatly expand total usage. Such designs are still in the evaluation stage and must receive approval from the AAR before they become standard equipment. The projection for 1973 is for only 30 cars per year, since considerable work still remains to be done. Alternates are steel and aluminum.

Railroad industry — rapid transit cars. In the last few years, probably no market has enjoyed more publicity than rapid transit. This is understandable since it is necessary to establish public awareness of the needs and potential solutions in order to raise the billions of dollars necessary to finance this growth market. Both stainless and aluminum will be used for construction of transit cars.

This market is estimated to have an annual growth of 5%. In 1966, stainless shipments to the market were 10,000 tons (equivalent to 1.2 million pounds of Ni). The forecast for 1973 is, therefore, 14,000 tons (equivalent to $1\frac{1}{4}$ million pounds of Ni). This market uses principally Types 301 and 201. Since the cars could be designed utilizing the higher strength of 201 compared to 301, this would be a logical application aside from the nickel conservation aspect. Aluminum or steel are contenders, if stainless were unavailable.

Desalination. A potential major growth market for stainless is desalination; however, between now and 1973 desalination will have little if any effect on total stainless usage. There is an AISI evaluation program now under way to establish the technical competence of stainless for various applications in desalting plants. Test results will not be known until almost 1972 at which time a proper evaluation can be made.

Potential Substitutions

For most applications, a 300 series (nickel-chromium-iron) steel can be replaced with the equivalent 200 series (manganese-chromium-nickel-iron). For example, Type 301 contains 17 Cr, 7 Ni; Type 201, 17 Cr, $4\frac{1}{2}$ Ni and $6\frac{1}{2}$ Mn. Most production of 200 steels has been in the two standard grades, 201 and 202, as shown in Table 9. Ingot production has been relatively small and not increasing over the years, despite a small price advantage favoring the 200 grades. While the corresponding alloys have similar properties, the manganese-nickel steels tend to be somewhat stronger and harder than the nickel stainlesses. Slightly greater forces are needed in fabrication, but yield and tensile strengths are correspondingly higher. Typical applications where the use of a 200 grade

TABLE 9

INGOT PRODUCTION TYPE 200 & 300
1957-1967
with projections 1968-1973

	200 Type	300 Type	200 Type as a % of 300 Type	Total 200-300 Ingot Production (Net Thousand Pounds)	Type 300 as a % of Total 200-300
1957	50,660	1,166,842	4.3%	1,217,502	95.8%
1958	62,454	1,081,676	5.8%	1,144,130	94.5%
1959	60,946	1,407,816	4.3%	1,468,762	95.9%
1960	50,064	1,260,360	4.0%	1,310,424	96.2%
1961	68,750	1,433,272	4.8%	1,502,022	95.4%
1962	83,704	1,328,890	6.3%	1,412,594	94.1%
1963	106,542	1,551,822	6.9%	1,658,364	93.6%
1964	98,178	1,970,782	5.0%	2,068,960	95.3%
1965	55,110	1,958,950	2.8%	2,014,060	97.3%
1966	49,062	2,330,180	2.1%	2,379,242	98.0%
1967	60,040	1,930,526	3.1%	1,990,566	97.0%
1968	88,000	1,956,000	4.5%	2,044,000	95.7%
1969	96,000	2,124,000	4.5%	2,220,000	95.7%
1970	100,000	2,228,000	4.5%	2,328,000	95.7%
1971	110,000	2,452,000	4.5%	2,562,000	95.7%
1972	122,000	2,696,000	4.5%	2,818,000	95.7%
1973	134,000	2,966,000	4.5%	3,100,000	95.7%

Source - Years 1957-67: AISI Form 104, Production of Stainless & Heat Resisting Steel Ingots.

is satisfactory or even preferable to a 300 grade are in truck trailer bodies, transit cars, architectural applications, and kitchen equipment. Considering the developments and modifications over the years, it is not inconceivable to expect that the 200 series could be substituted for 75% of the 300 series applications. However, the corrosion behavior of the 200 series is not yet well defined. Most applications where these steels have been used have been those in which the corrosive environment is not severe. Corrosion-resisting behavior can be expected to approximate that of the better known 300 steels; test data and service experience to confirm the expectation are just much more limited.

During the nickel shortage at the time of the Korean War, a 16 Cr, 16 Mn, 1 Ni steel was produced. The corrosion resisting properties of this composition were satisfactory, but the steel is hot short and thus extremely difficult to roll. Recent work, not yet out of the development phase, shows promise in a composition of 6½ Ni, 26 Cr, having a fine-grain, duplex microstructure.

Complete removal of nickel from the alloy results in a ferritic rather than an austenitic structure. Such steels (400 series) have properties and corrosion resistances which differ considerably from those of the 300 series nickel-containing grades. Fabrication of the 400 series is more difficult, ruling out some applications and making others more expensive.

Going further afield, substitution for a nickel-bearing stainless steel can sometimes be made by an alloy or carbon steel, brass, aluminum, titanium, or even a plastic. Performance penalties, or shorter life, would nearly always be associated with such changes due to greater corrosion or lower strength.

B. Nickel Usage in Alloy Wrought Steels

The American Iron and Steel Institute tonnage reports reflect nickel-bearing steels in five grade groupings, namely, Ni, Ni-Cr, Ni-Mo, Ni-Cr-Mo-V, and Ni-Cr-Mo. In certain of these, boron modifications exist. So as to relate to data made available to the Subcommittee on Nickel, the 1966 AISI data were

examined. Total production reported for 1966 in the nickel-bearing steel categories was 2,511,773 mill product tons. Across this tonnage, nickel usage would reduce to an average nickel content of .62%.

Automotive Industry

This subject is handled in detail in section IV C. The trend in the automotive industry since World War II has been to the use of leaner alloy steels and carbon steels, and it is expected that this trend will continue. Only one manufacturer continues to use the nickel-bearing 4626 (Ni 1.65/2.00) for ringgears. While some 8620 (Ni .40/.70) is used for special carburized parts, the main automotive usage of this grade is for carburized bearings. Substitutions of grades with reduced nickel or free of nickel could undoubtedly be made, but as with all substitutions this would entail lead time and added cost.

Trucking Industry

The trend in the trucking industry during the past few years has been to greater use of the Interstate Hyghway System. This has resulted in sustained higher speeds and rapid accumulation of mileage. Thus, a truck may accumulate 150,000 miles in one year when it used to take several years. Product warranty and reliability are becoming more critical in this industry and there may be a trend to use more and richer nickel-bearing steels. Common practice today would show the following nickel-bearing grades in use:

1. Gearing

Transmission - 8620 (Ni .40/.70), 4620 (Ni 1.65/2.00), 4320 (Ni 1.65/2.00), 4820 (Ni 3.25/3.75), and 3312 (Ni 3.25/3.75)

Differential - 94B17 (Ni .30/.60), 8620, 8622, 8822 (Ni .40/.70), and 4817 (Ni 3.25/3.75)

2. Engines

Camshafts - 8620, 8622 (Ni 0.4/0.7)

Fuel Injector Parts - Krupp Analysis (Ni 4.25), 3312 (Ni 3.25/3.75), 4317 (Ni 1.65/2.0), and 9310 (Ni 3.00/3.50)

Piston Pins - 8620, 4620 (Ni 0.4/0.7 and 1.65/2)

Push Rods - 8645, 8620 (Ni 0.4/0.7)

Rocker Arms - 8620 (Ni 0.4/0.7)

In view of the trend to high speeds, higher loading and the necessity for longer life, it would be assumed that grade changes would result in greater nickel usage, rather than less.

Even when gross weight limits do not apply, the maximum useful load on heavy-duty trucks and trailers is largely dependent on the empty weight of the equipment. Economics and sound engineering dictate the use of welded hybrid designs, which largely involve the use of the quenched and tempered plate steels, some of which are nickel-bearing. Such applications are now commonplace in huge trailer trucks, in main frame members of flatbed trailers, and in the framing and bodies of huge off-highway equipment. This usage would be expected to expand.

Aircraft and Aero- and Hydrospace Industries

These topics are discussed in detail in Section IV B. The aircraft industry has always made every effort to reduce weight; and during the last decade a number of steels have been developed for use at strength levels up to 300, 000 psi yield strength, with enough toughness to provide a useful part. Landing gear parts are currently forged from 4340 (Ni 1.65/2.00), D6AC (Ni .40/.70), 300M (Ni 1.65/2.00), or AMS-6427 (Ni 1.65/2.00) all melted in electric furnaces and often vacuum arc remelted. Aircraft bearings, shafting and gearing frequently use 9310 EF (Ni 3.00/3.50) Aircraft Quality (ACQ), and the 18% Ni maraging steels are finding increasing application. The trend would appear to be toward greater use of nickel, combined with vacuum melting techniques, to provide materials of extremely high strength with reasonably good toughness.

An examination of the SAE Index of Aerospace Material Specifications (November 1, 1967) covering Wrought Low Alloy Steels (AMS 6242 - AMS 6550) reveals that 64, of the 117 total, define nickel-bearing steels. Nickel contents range from a low of .25/.65 to a high of 7.00/9.00.

The Aerospace Industry has used 4335 V (Ni 1.65/2.00), D6AC (Ni .40/.70), maraging and other high strength steels to provide light weight, high strength motor cases ranging in size from the Saturn down to the Bazooka. The motor case, being a pressure vessel, must withstand high internal pressure during firing. Thus, to reduce weight, the highest possible strength is required in thin sections. The maraging steels have proven useful because of their ease of heat treatment in these large and unwieldly parts, and because of superior toughness at high strength levels.

The Hydrospace Industry is principally concerned with high toughness at high strength levels, but generally strength will be sacrificed for improved toughness. The HY-80 (Ni 2.00/3.25) grade has long been used in submarines and only recently have higher strength materials been developed with sufficient toughness to satisfy the Navy. With the current striving for deep submergence, the 18% Ni maraging steels and a series of grades — HY-110 (Ni 2.25/3.50), HY-130 (Ni 4.75/5.25), HY-180/210 (Ni 10%) — with increasing nickel contents are under test.

Marine Transportation

The basic material of construction for marine service is carbon steel. This is true because it gives the user and designer much of what is needed at a minimal cost. Corrosion behavior becomes a significant factor in any consideration to upgrade to more durable materials. Small amounts of copper and nickel, used in the low-alloy steels (ABS Section 39, High Strength Steels), enhance their corrosion resistance in marine atmospheres, by producing a tighter, denser film which has less tendency to leach away, or spall.(1) Certain quenched-and-tempered nickel-bearing steels have found use where a weight savings can be gained through their higher strength. Typical applications include hatch covers, free-standing booms, and slamming-damage areas.

In the broad category of marine transportation, but within a specific area of submarine hull plate, there is a considerable usage of HY-80 armor plate

steel (2.75 Ni). This material features a high resistance to initiation and propagation of fracture in service. As usage presses toward more critical service, the need for higher strength levels, accompanied by adequate toughness, brings richer nickel-bearing steels into play. These steels, just recently developed, have been designated HY 130/150 (5.00 Ni) and HY 180/210 (10.00 Ni). These designations, as was the case with the HY 80 material, define minimum yield strength. Increased usage of these higher strength steels, and therefore of nickel, is anticipated.

There has been usage of nickel (2.5 Ni) in ship shafting. However, in times of nickel shortage a Mo-V grade has been substituted, and there should be no need to revert to the use of the nickel-bearing grade.

Electrical and Electronics Equipment

This category covers a wide range of products which serve to either produce, transmit or consume electricity. To the steel producer, this activity is considered as extremely important, being the fifth largest steel consuming industry. Of the estimated 5,000,000 tons of steel directed towards this industry, approximately 11% is in the form of alloy wrought products. Within this latter category, the principal items involving the use of Ni steels are turbine rotors, generator rotors, and turbine wheels and discs. It is estimated that approximately 20,000 tons per year are utilized in these categories as heavy forgings. This figure should remain quite stable over the next five years. All of these latter requirements incorporate Ni-bearing grades, generally 2.00/3.00 Ni. The trend is toward larger turbines and generators which will require even richer Ni-bearing steels. These heavy forgings are covered by the following ASTM specifications or slight modifications thereof:

ASTM A-292 (2.00 or 2.50 min. Ni)
A-293 (2.00 or 2.50 min. Ni)
A-294 (1.50/3.50 or 1.65/3.50 Ni)
A-469 (2.50 min., 3.00 min., or 3.25/4.00 Ni)
A-470 (2.50 min., 3.25/4.00 Ni)
A-471 (2.00/4.00 Ni)

The advent of nuclear power systems should result in substantial usage of the aforementioned type of forgings, and Ni-Cr-Mo plates such as ASTM A-543 (ASME 1358) (2.60/3.25 or 3.00/4.00 Ni).

Agricultural and Heavy Construction Equipment

Agricultural tractors and equipment have developed rapidly in response to the need for greater power and increased speed. In many cases the "new, more powerful tractor" has been obtained by increasing the horsepower of the engine and delivering that power through the old transmission and differential. This increased gear loading frequently necessitates higher nickel steels for the gears. However, when re-design of the transmission is necessary for the new generation of tractors, the ability to increase size may enable the manufacturer to return to the lower nickel steels.

Currently, the carburizing grades used include 8620 (Ni .40/.70), 8822 (Ni .40/.70), 4320 (Ni 1.65/2.00), and 4817 (Ni 3.25/3.75). The through-hardening grades include 4340 (Ni 1.65/2.00) and 8645 (Ni .40/.70) for heavy axles and shafting.

The heavy construction equipment industry has placed greater emphasis on toughness than the agricultural group because of the great temperature extremes encountered, and increased severity of the service. This has resulted in a greater usage of nickel-bearing steels for gearing and other critical parts. As the equipment becomes larger, increased usage of nickel steels can be expected.

Equipment used to haul earth and rock is subjected to severe abrasive wear and impact abrasion. The trend appears to be to higher carbon contents, higher hardness, and improved toughness. This toughness consideration may well require higher nickel contents.

Mining and Drilling Machinery

Mechanized mining operations have been developing rapidly since World War II and the trend is to larger, more powerful and higher-speed equipment, with less downtime for maintenance. These result in greater demands on

the power plant gearing and those parts exposed to abrasion. The drilling industry consumes considerable quantities of AISI 8720 (0.20 C, 0.6 Ni, 0.5 Cr, 0.25 Mo), and 4815 (0.15 C, 3.5 Ni, 0.25 Mo) for drill bit components. These steels are used to provide an adequate combination of toughness and hardenability.

Carburized parts such as gears, bearings, rock drill parts and some shafting are commonly produced from 8620 (Ni .40/.70) today, with extreme service parts requiring 4620 (Ni 1.65/2.00) or 4820 (Ni 3.25/3.75). As these parts increase in size to meet the new service requirements, increased alloy content, including nickel, will be required to provide hardenability and toughness.

Through-hardening nickel steels for shafts, heavy gearing, bucket teeth and booms have commonly been 4340 (Ni 1.65/2.00), 8640, and 8660 (Ni .40/.70). Increases in size and the necessity to provide improved notch toughness would require materials such as 300-M (Ni 1.65/2.00) or D6-A (Ni .40/.70).

Abrasive wear and impact loading become more severe as the capacity and speed of operation of the equipment increase. This will require through-hardened wear plates at higher carbon levels with substantially increased hardness and sufficient toughness to withstand the impact loading. This will require higher nickel steels.

Metalworking Equipment

Nickel-bearing steels are used extensively in metalworking equipment. These are primarily used for bearings, chucks, clutches, collets, gears, pumps, slides and spindles. These applications are common to such equipment as turret lathes, milling machines, grinders and rolling equipment. While numerous grades are used, 4820 (3.25/3.75 Ni) and 8620 (0.40/0.70 Ni) are used mainly for the carburizing applications and 4340 (1.65/2.00 Ni) and 8640 (0.40/0.70 Ni) are used where through-hardened steels are required. It is felt that should the occasion demand, higher Mo contents could be used to replace the current nickel levels in the aforementioned analyses. While the projected growth rate for metalworking equipment for the next five years is expected to be at an annual rate of

2.7%,[2] the changes being brought about by the use of numerically controlled equipment could cause this to increase substantially.

Petroleum and Chemical Manufacturing Equipment

In the area of petroleum and chemical manufacturing equipment we are largely concerned with a variety of pressure vessels fabricated from plates. The nickel-bearing alloy steels have no place in high-temperature applications, but they are found in the low-temperature field. We find the 2-1/4% nickel steels serving to temperatures of -75°F, the 3-1/2% nickel steels serving to temperatures as low as -150°F, and the 9% nickel steels being used down to -320°F. Investigative work at U. S. Steel and Inco has indicated a potential of 8% nickel steel serving the purpose of the 9% nickel steels, at least through a significant portion of the -150°F to -320°F range. Should nickel shortages become quite critical, aluminum alloys can be used rather than the 9% nickel steels, although fabrication in that case would tend to be more costly.

In sour crude oil-well pumping applications there has been use of nickel-bearing compositions 4620-21 (1.65/2.00 Ni) through the years. There is some usage of 8620 (.40/.70 Ni) in sucker rods. A new nickel-bearing grade (.35 C, 1-1/2 Ni, .75 Cr) is showing promise in general use in sucker rods, and this may well result in increased consumption of nickel across the industry.

While generalization is risky, it would appear that more critical service requirements across a major portion of the applications examined point to the probability of an increase in over-all nickel content in the wrought alloy steels. There appears to be no way of being quantitative concerning the effect of this probability.

Substitutions

Nickel in alloy steel performs a number of functions:

1. The composition provides a good combination of properties in case and core of carburized steel (nickel is not a carbide former).

2. Toughness at low temperatures results because a given level of hardness and strength is obtainable with a considerably lower carbon content (nickel strengthens ferrite).

3. Corrosion and stress-corrosion are reduced even when nickel is present in the usual 0.5-5% amounts.

4. Lowering of the eutectoid temperature minimizes scaling and warpage during heat treatment.

There are alternative ways of obtaining any of the above objectives; such as by the use of other alloy ingredients such as chromium or molybdenum, or by the use of a coating. Alternatively, one could tolerate a slightly inferior product. With present price structures, nickel happens to accomplish the job most economically; it is not unique or irreplaceable in steel. In time of emergency, alternate ferroalloys might be just as limited as nickel. If conservation were needed, a first step might well be in the direction of leaner alloys of the NE types. These might require more drastic quenching for hardening, leading to distortion and the possibility of cracking. Excessive reduction of alloy ingredients like nickel could well prove, however, to be false economy. Some substitution possibilities are outlined in the table in the conclusion section of this report.

REFERENCES

1. Guidelines for Selection of Marine Materials, A. H. Tuthill and C. M. Schillmoller, Inco publication, 1966.

2. "How Technology Helps Brighten A Forecast," Business Week, June 15, 1968, page 126.

C. Trends in the Usage of Nickel in Electrical, Magnetic, and Expansion Alloys

The term Electrical Alloys in trade terminology describes those nickel-iron alloys used as glass-to-metal sealing alloys, or as core materials in various magnetic circuits. The glass-to-metal sealing alloys are used in the range of 42% nickel up to 52% nickel and the magnetic materials at 50% nickel up to 80% nickel. Glass-to-metal sealing alloys provide the mechanism whereby one can conduct an electric current into or out of an encapsulated area such as a vacuum tube, a cathode ray tube, a reed relay, etc. The magnetic material is used in various forms such as laminations, wound cores, sheets, bars, or wires to amplify a signal, convert electrical energy to mechanical energy, prevent a magnetic field from reaching a sensitive device, etc.

Another group, electrical resistance alloys, can be divided into three categories. One group is designed for electric-resistance heating applications. Some members of this group are capable of operating at temperatures up to 2300°F. The basic alloy is 80 nickel-20 chromium. Several of the materials are nickel-chromium-iron alloys; others are nickel-silicon, nickel-aluminum-silicon, and nickel-chromium-columbium-silicon alloys. Another group is designed for electrical resistance applications at or near room temperature. Such materials are nickel-chromium, nickel-chromium-iron, nickel-chromium-iron-aluminum, and nickel-chromium-manganese-molbydenum alloys. The third category serves thermocouple and thermopile applications. Examples of alloys in this group are 91 nickel-9 chromium and 95 nickel-5 aluminum. In a number of applications, the nickel-base electrical alloys could be replaced by iron-chromium-aluminum alloys, chromium stainless steels, and chromium-nickel stainless steels. Penalties, such as the necessity to redesign the equipment or the component, or the necessity to accept shortened life, would be incurred in most replacement situations. The technology of the electrical alloys seems to be on a plateau at the moment.

The majority of the alloys having controlled coefficients of thermal expansion are members of the nickel-iron system to which other elements such as cobalt, chromium, titanium, manganese, tungsten, and molybdenum often are added. The 36 nickel-64 iron binary alloy, Invar, is the progenitor of the family. Other prominent members of the group are Elinvar and age-hardenable alloy, Ni-Span C. A well developed technology encompasses these alloys.

Nickel Projections

The following table lists the nickel consumed in the year 1967 in pounds:

Year	Glass-to-Metal Sealing	High Permeability Alloys	Resistance
1967	2,487,000	5,500,000	12,000,000

A growth rate of 7% per year can be anticipated for electrical alloys. However, due to the present demands for nickel, it is estimated that only sufficient nickel will be available to permit 5% growth per year for several years.

Market Projections

The use of nickel in electrical alloys depends on either its physical or ferromagnetic properties. Our knowledge to date says that there are no known substitutes for nickel which can satisfactorily duplicate the thermal expansion properties or the magnetic characteristics of the nickel-iron alloys.

Sealing alloys. The sealing alloys are used because of the close match between the thermal expansion properties of certain glasses and particularly of these alloys. Certain packaged electronics using lead frames made of the 29% Ni- 17% Co- Bal. Fe alloy are gradually converting to the 42% Ni alloy, but this may be only temporary, since ultimately a portion of the market is expected to use high-purity iron. This transition may take place by about 1973. Other areas which are required to continue to use certain soft glasses must also continue to use the low expansion nickel-iron alloys and no substitutes, per se, are apparent.

High permeability alloys. There are only four known ferromagnetic metals in the pure state and two additional ones in the combined state. They are:

1. Iron
2. Cobalt
3. Nickel
4. Gadolinium (rare earth)
5. Manganese when alloyed or in the combined state
6. Chromium in some alloyed state

A ferromagnetic material must contain one of the first five metals above. Various combinations of these metals have been examined and reported in the literature and it can be concluded that there are no substitutes for nickel insofar as producing those special magnetic characteristics described by the nickel-iron alloys.

Even though miniaturization would tend to depress the amount of nickel used, the preponderance and variety of devices being made today would counterbalance this trend. Magnetic shielding is rapidly increasing and is essential for proper operation of certain sensitive devices in missiles, computers, oscilloscopes, etc. Further increases are seen in the general increase of electrical equipment. These trends will easily account for the 7% projected increase in the use of nickel in this industry.

Other markets. Related to the Electrical Industry is the transistor. Production of high-purity nickel cans for transistors has been decreasing from a current 750,000 pounds per year to an anticipated floor of about 200,000 pounds per year. This is due to advanced technology and improvements in the state of the art requiring less nickel to produce more transistor cans.

Another area where nickel requirements may continue in high demand is in permanent magnets. Most recently ceramic magnets have been replacing the Alnicos, in part due to the nickel shortage. However, computer-designed permanent magnet motors suggest that the Alnicos are capable of producing a far superior motor than the ceramic magnet type.

Further increases in the use of nickel can be anticipated in new devices. Reports indicate that the telephone receivers which now use a cobalt-iron magnetic sensor will eventually be converted to a nickel-iron device for greater sensitivity

and a higher degree of reliability. The Vidiophone will require additional usage of nickel-iron alloys. New transducer devices of the high energy type for deep sea exploration appears to be made of a high nickel alloy and considerable usage is anticipated in this application.

D. The Cupronickels

High Copper Types

Because of the favorable combinations of properties they possess, the cupronickels have become well established in a considerable variety of important applications. Alloys of the 90 copper-10 nickel and 70 copper-30 nickel types enjoy superior resistance to general corrosion as well as to stress-corrosion cracking in a number of media, particularly, saline waters. In addition, these alloys have good room-temperature strength and ductility, do not undergo a ductile-to-brittle transition, have good anti-fouling characteristics, retain useful strength at temperatures up to about 700°F, are readily formed and welded, and are reasonable in cost.[1]

Continued research and development are making the technical position of these alloys increasingly secure. It has been found, for example, that small additions of iron greatly enhance the corrosion resistance of the alloys, especially in dynamic systems. On the basis of this finding, a 90-10 alloy containing 1.5% iron and a 70-30 alloy containing 0.5% iron were developed during the 1940's.[2] In addition, it has been observed that the 70-30 alloy can be rendered age hardenable by the addition of 0.5% beryllium.[3] The addition of 5% iron to the 70-30 alloy enhances both its strength and its resistance to erosion-corrosion in flowing seawater.[4] Still other developments directed at increasing the strength of these types of cupronickel alloy are currently in progress.[5]

Both the 90-10 and the 70-30 types of cupronickel have gained wide acceptance for components of condensers, heat exchangers, and other heat transfer equipment, especially where the media are water or steam. In such applications,

they are employed both in wrought and in cast forms. The 90-10 alloy modified with 1.5% iron is understood to be favored by the United States Navy for shipboard condensers.[6] These types of alloy also have become well established in the chemical, petroleum, and petrochemical industries for similar applications.

More recently, these alloys have been finding applications in hydrospace. For example, AISI Type 304 stainless steel wire clad with 90-10 cupronickel has been reported to be attractive for oceanographic wire and cable as well as for guy wire, logging cable, and aircraft control cables.[7] Again, the cupronickels are suitable for sheathing harbor pilings. The 70-30 alloy modified with the addition of 0.5% beryllium has been used successfully for the housings of deeply submerged hydrophones, and certainly this type of alloy could be used to encapsulate many other devices of an oceanographic, military, or industrial nature requiring submergence in the sea.[8]

Another area that has begun to consume substantial quantities of cupronickel is the desalination or conversion of seawater into fresh water. Though the technology of large-scale conversion is still in its formative period, a number of commercial-scale desalination plants are in various stages of design and construction. And it is clearly evident that quite a number of very large installations will soon be required in various parts of the world. The currently preferred material for the enormous quantities of heat exchanger tubing and tube sheets that will be needed is the 90-10 alloy containing 1.5% iron.[2] For example, the one-million-gallon-per-day Clair Engle desalting plant that was dedicated in August, 1967 at San Diego, California, contained 234 miles (1.25 million feet) of 90-10 cupronickel condenser tubing.[9] This plant is a prototype, in a sense, for the 150-million-gallon-per-day Bolsa Island Nuclear Power and Desalting Plant planned by the Metropolitan Water District of Southern California and scheduled for operation in the spring of 1973. This plant reportedly will use 30 million pounds of cupronickel tubing.[10] Assuming all the tubing to be of the 90-10 alloy, the contained nickel in this quantity of material will be approximately 3 million pounds.

One source has estimated the ten-year potential for cupronickel tubing in desalination plants at 400 million pounds.(10) If the tubing is primarily of the 90-10 variety, then the amount of nickel contained would be approximately 40 million pounds, or 4 million pounds per year. Thus, the planned activity in the field of desalination alone may increase the annual consumption of nickel in the form of cupronickel from the 8.2 million pound level of 1966 to 12 or more million pounds.

On the other hand, the cupronickels do not have the field to themselves. Other alloys are used for condenser and heat exchanger tubing, the principal one for installations involving seawater being aluminum brass.(11) A recently published survey(12) by A. D. Little, Cambridge, Mass., of materials performance in 55 land-based desalination plants, attested to the excellent corrosion behavior (less than 1% tube failures) of both 90-10 copper-nickel and aluminum brass in this service. Most service experience is available on arsenical aluminum brass. As a compromise between cost savings and service behavior, the Little report recommended use of Al brass tubes in the reject stages (10% of plant), 90-10 Cu-Ni in the recovery stages (85% of plant) and 70-30 Cu-Ni in the brine heaters. So far as large desalination installations are concerned, titanium alloys are making a bid. These alloys have been at a disadvantage because of their higher cost, because of their possible susceptibility to crevice corrosion, and because they are difficult to form and join. Crevice corrosion problems can be alleviated through suitable changes in the design of the components involved. In addition, such alloys as Ti-2Ni and Ti-2Mo appear to be resistant to crevice corrosion and they, or some modification of them, may ultimately become competitive with the cupronickels.(13) Again, competition may come from still other alloys such as iron-containing copper and iron-containing aluminum brass.(6)

The 45 Nickel Types

The type of cupronickel alloy containing nominally 45% nickel also enjoys an established reputation and a considerable spectrum of applications. Usage of these alloys is based on such properties as thermal EMF, electrical

resistivity, temperature coefficient of electrical resistance, capability to be brazed, nonmagnetic character, capability to withstand elevated temperatures, high strength, and resistance to stress-corrosion cracking.[14] The principal applications for these alloys are thermocouples, thermopiles, and resistors. They are most commonly produced in the form of wire, flattened wire, and ribbon.

While the producers of these alloys continually improve them, it does not appear that a dramatic break-through or a radical change in their usage pattern is to be expected in the near future. On the other hand, they do not seem to have competition from any low-nickel or nickel-free materials.

The consumption of these alloys is closely related to the level of activity in the field of electrical and electronic equipment. Because this field is constantly expanding, the consumption of the 45-nickel type of cupronickel can be expected to show a significant steady increase year by year. An increase of 5 to 10% per year does not seem unreasonable. Based on a consumption of about 2.6 million pounds of nickel in these alloys in 1966, this amounts to a minimum initial increment of 260,000 pounds of nickel.

<u>Summary</u>

Taking all factors at face value, it can be speculated that the amount of nickel to be consumed in the form of cupronickel during the next few years will be somewhat as indicated in Table 10. However, the estimates given may be high. Perhaps, a better estimate for total nickel consumption should be one or two million pounds per year less than indicated in the Table. Such will certainly be the case should nickel-free alloys capture an appreciable share of the market for heat transfer tubing in desalination plants.

TABLE 10. ESTIMATED UNITED STATES CONSUMPTION OF NICKEL IN THE FORM OF CUPRONICKEL (Pounds)

Year	High Copper	45-Nickel[a]	Total
1966	5,600,000	2,600,000	8,200,000
1967	6,600,000[b]	2,860,000	9,460,000
1968	10,600,000	3,150,000	13,750,000
1969	11,600,000	3,460,000	15,060,000
1970	12,800,000	3,810,000	16,610,000
1971	14,100,000	4,190,000	18,290,000
1972	15,500,000	4,610,000	20,110,000
1973	17,100,000	5,070,000	22,170,000

(a) An annual increase of about 10 percent is assumed.

(b) It is assumed that the full impact of seawater-conversion plant construction is not felt till 1968. Also, an annual increase of 10 percent for all other applications is assumed.

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E. Other Nonferrous Alloys

The Monels

The original Monel alloy was essentially a binary solid solution alloy composed of approximately two-thirds nickel and one-third copper. It was extremely tough, displayed good strength and ductility in the annealed condition, could be strain hardened to considerable strength, could be fabricated readily, and displayed excellent resistance to corrosion in a variety of important media.

Since the introduction in the early 1920's of this alloy, now known as Monel alloy 400, numerous modifications have been developed, each with special characteristics. For example, Monel alloy 402, containing about 40 percent copper, is designed for use in the pickling of steel. It is resistant to hot sulfuric acid pickling solutions and to hydrogen embrittlement when galvanically coupled to steel. Monel alloy 403 was developed as a nonmagnetic material for use in mine sweepers. Monel alloy 404 has low magnetic permeability and good brazing characteristics, while Monel alloy R-405 is similar to alloy 400 but possesses improved machinability. Monel alloy 406 is used primarily where resistance to certain extremely corrosive mineral waters is required. Monel alloy K-500 and 502 are corrosion resistant, nonmagnetic, and age hardenable to high strength levels.

Because of their specific corrosion resistance, ease of fabrication, and good strength, the Monel alloys enjoy a stable diverse market. One of the largest fields of application for these alloys is chemical process equipment handling fluorides; others are equipment used in the salt and potash industries. Other strong markets are feed water heaters and power plant heat exchangers. Technical developments that would alter sharply the usage pattern of the Monel alloys are not expected. Instead, a small but steady increase in the consumption of these alloys is looked for.

Regarding possible substitutes for these alloys, no categorical statements can be made. Each major application would have to be considered on its

own merits. Potential substitutes would probably be found among copper-base alloys, stainless steels, and perhaps titanium and its alloys. It would be expected that substitutions would generally entail a sacrifice in performance (principally, corrosion resistance) and sometimes an increase in costs. It would appear that one of the most difficult areas in which to find satisfactory substitutes would be in processes and systems involving fluorides.

A 1953 MMAB report entitled Salt Water Valve Stems and Trim contained a listing of possible substitutes for monel for the indicated application. These possibilities are reproduced as Table 11.

The Nickel Silvers

The family of copper-nickel-zinc alloys that has become known as the nickel-silvers is an extremely versatile group of materials. These alloys feature a high degree of corrosion resistance, ease of fabrication and joining, excellent spring properties, amenability toward electropolishing, attractive color, high strength, and moderate cost.[1,2] They are available in the form of castings as well as in a wide variety of wrought forms.

A classical application for the nickel silvers is silver-plated flatware and hollow-ware. Here, one of the most important factors is color. When the silver plating wears away in the course of time on especially vulnerable edges and surfaces, thus exposing the nickel-silver substrate, the resulting color contrast generally is not objectionable. Other long established fields of application include architechtural trim and hardware, keys, locks, and small machined parts.

In recent decades, these alloys have enjoyed a substantial expansion in the spectrum of their applications. They have found usage as valves and fittings for dairy, bottling, and food packaging equipment; diaphragms and spring parts for optical equipment; fittings for fishing reels and rods; as well as faucets. washbowls, flush valves, and domestic hardware items.[3] Other applications include contact springs, wiper blades, and containers for telecommunication equipment; components of glasses frames; zipper fasteners; cigarette lighters,

TABLE 11

POSSIBLE SUBSTITUTE MATERIALS FOR MONEL VALVE COMPONENTS****

I. Copper Base Bodies (Usually Composition M or G Bronze)

A. Seats and Discs

Throttling Valves	Non-Throttling Valves
1. 5Ni-10Al-3Fe-Cu (cast)*	1. All alloys listed to left under "Throttling Valves" except No. 8
2. 30Ni-0.5Fe-1.5Al-Cu (cast or wrought)*	2. 10Ni-1Fe-1.5Al-Cu
3. 30Ni-4.5Sn-1 max. Fe-0.75Si-Cu (cast)**	3. 10Ni-1.25Fe-Cu
4. 50Ni-2.5Si-Cu (cast)	4. 30Ni-0.5Fe-Cu
5. 52Ni-12Sn-0.75P-Cu (cast)	5. Composition G Bronze
6. 45Ni-1.5Fe-Cu (cast or wrought)	6. Composition M Bronze
7. S-Monel-3.5 to 4.0Si substituted for Ni (cast)	7. Silicon Bronze 3.2Si-15Zn-Cu-low Pb***
8. 29 Ni-20Cr-3Cu-3Mo-1Si-Fe (cast or wrought)	
9. 8Al-2.5Fe-Cu	
10. Titanium	
11. Non-metal Composition, E. G. nylon	
12. Silver Alloys	
13. Hastelloy C, Illium, Stellite and related alloys	
14. Carbides	

B. Stems (For both throttling and non-throttling service)

1. 30Ni-0.5Fe-1.5Al-Cu (cast or wrought)**
2. 45Ni-1.5Fe-Cu (cast or wrought)
3. 29Ni-20Cr-3Cu-3Mo-1Si-Fe
4. 8Al-2.5Fe-Cu
5. 9.5Al-5.0Ni-2.5Fe-1.0Mn-Cu
6. Titanium
7. 10Ni-1.25Fe-Cu
8. 30Ni-0.5Fe-Cu
9. Composition M Bronze
10. Silicon Bronze 3.2 Si-15Zn-Cu-low Pb***
11. Phosphor Bronze 10Sn-0.25P-Cu

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* Possible but should be checked by tests in actual valves

** May contain Pb up to 2.5% and small amounts of P and/or Mn

*** Substituted for composition "M" on Merchant Marine applications in World War II

**** Sequence is of no significance

TABLE 11 (Cont'd)

POSSIBLE SUBSTITUTE MATERIALS FOR MONEL VALVE COMPONENTS

Throttling Valves	Non-Throttling Valves

II. Steel Bodies (For both throttling and non-throttling service)

A. Seats, Discs and Stems

1. All materials listed above under 1-A for throttling and non-throttling service as Seats and Discs (performance of these materials will be better in this case than when copper-base body is used).

2. Standard brass trim and stems.

NOTE: In smaller size valves, use thickest wall size for body that is available. Minimum wall thickness should be specified as 3/8-inch thick. In event copper piping is employed with steel-body valves, insert steel wasterpieces, minimum length 6 pipe diameters, double extra heavy wall or both sides of valves. Provide spare pieces on ship for immediate replacement as required.

and jewelry.[1] Additional applications are diode cans, supports and spring clips, leaf and wire springs, electron tube pins and receptacles, fluorescent tube springs, diode stick frames, connectors, terminals, and contact points. These items are used in automobiles, telephone systems, computers, refrigerators, and television sets.[2]

According to one report, the amount of nickel silver used for electrical and electronic applications in 1963 and in 1965 was 3.6 million pounds and 7.1 million pounds, respectively.[2] Assuming an average of 15% contained nickel, this means a consumption of 540,000 pounds of nickel in 1963 and 1,085,000 pounds of nickel in 1965. The consumption of nickel in this category in 1966 was 1.3 million pounds. These consumption figures factor out to an annual increase in nickel usage in this category of about 250,000 pounds.

The field of appliances, utensils, and service machinery has constituted the other large consumer of the nickel silvers, accounting for approximately 1.2 million pounds of contained nickel in 1966. Since World War II, inroads have steadily been made into this field by the stainless steels, and it is doubtful that the area can any longer be considered a growth area for the nickel silvers.

In sum, it is estimated that the consumption of nickel in the form of nickel silver can be expected to increase moderately during the coming years, perhaps at the rate of 250,000 to 300,000 pounds per year.

Cast Brasses and Bronzes

Nickel is used in a number of cast brasses and bronzes. For example, some tin bronzes contain up to 4% nickel, while nickel-containing aluminum brasses and manganese-aluminum brasses are quite common. In addition, nickel is an ingredient of a number of special copper-base alloys such as White Tombasil, a corrosion resistant cast alloy,[4] and Incramet 800, a material developed for glass molds.[5]

The nickel-containing brasses and bronzes apparently enjoy a considerable variety of applications. Nickel-tin bronzes are used for bearings,[6] while

nickel-aluminum brasses are favored for ship propellers.[7, 8] However, no data have been found as yet that are suitable for use in projecting the consumption of nickel in such alloys during the coming years.

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F. Nickel Usage in Sand and Investment Castings

Of the estimated 397 million pounds of nickel consumed in 1966 by U.S. fabricating industries, 51 million pounds were used in the production of castings. There are six basic sand casting categories and two investment casting categories where nickel is used for the production of parts. Due to different sources being used for the various data included below, it was not possible to obtain a close correlation; however, the numbers are probably representative.

Sand Casting

Within the categories under this general heading are included other casting processes, such as shell molding. These are differentiated from the precision investment casting "shell castings" which are included later in this chapter.

Heat resistant castings. Approximately 13 million pounds of nickel are used per year for the production of heat resistant castings. Of this amount, approximately 50% is utilized in petroleum and chemical manufacturing equipment. Process industry equipment accounts for another 4.4 million pounds, with the next large quantity, 1.2 million pounds, being used largely in heat treating equipment, in the manufacturing of motor vehicles. It is estimated that the requirement for nickel used in the manufacturing of heat resistant castings is increasing at the rate of 10-12% per year. This growth is divided between new users and those who are upgrading and therefore using a higher percentage of nickel. It is interesting to note that seven years ago the percentage of nickel in heat resistant castings was between 8-12% — it is now on the order of 22%. The 25% chromium, 20% nickel iron-base alloy offers better thermal fatigue than the previously used materials. Typical parts are cast furnace tubes for refineries and chains and trays used in heat treating equipment. In the automotive industry, there is a substantial amount of nickel used in automobile exhaust valves and valve seats. It has been estimated that 3/4 of the parts produced in the heat resistant and corrosion resistant categories are utilized in production equipment, as opposed to units which become part of an end product.

<u>Corrosion resistant castings.</u> Estimated annual nickel requirements are 7.4 million pounds per year of which 4.2 million pounds per year are utilized in petroleum and chemical manufacturing equipment and 2 million pounds in process industrial equipment. Corrosion resistant castings have exhibited an annual growth rate of between 3-4% per year. As with heat resistant castings, this is divided between new applications and upgraded materials. The primary applications are in chemical processing plants, petroleum refineries and other areas where corrosive materials are handled. While the replacement market is a factor, the bulk of the production is required at the time the plants are initially equipped.

<u>Alloy steel castings.</u> Primary applications are in agricultural, mining and construction equipment, which account for approximately one-third of the nickel utilized in alloy steel castings. The other large users are producers of metal working equipment, consuming slightly under one million pounds of nickel per year. The applications are roughly equally divided between heavy frames and rolls for steel mills, railroad car undercarriages and lastly, construction machinery, such as tractors and earth moving equipment. Alloy steel castings maintain approximately the same percentage of the market each year with no specific trends; they had their peak year in 1943, due to production of armor plate and tank treads. Current total usage is about 3.8 million pounds per year.

<u>Gray iron castings.</u> Annual consumption rate is 10.8 million pounds per year. The largest use is in motor vehicles at a rate of 1.9 million pounds per year. Other large uses are in agricultural, mining and construction equipment (1.6 million pounds per year), metal working equipment (1.5 million pounds per year), and petroleum and chemical manufacturing equipment (1.0 million pounds per year). Nickel alloyed cast iron has 1/4-2% nickel added to improve the strength and soundness of the castings. Parts produced in these alloys are used in machine tool frames, foundry metal working equipment and rolls for steel mills, where basic gray or cast iron lacks the necessary mechanical properties.

It is also possible to utilize thinner sections due to the increased strength. Improved resistance to leakage is important in pump housings and hydraulic components.

Ni-resist irons (high nickel alloy cast irons with sufficient nickel (15-20%) to produce an austenitic metal structure) provide heat and corrosion resistance. Parts produced in these materials are used in the chemical and petroleum industries, as piston ring and piston ring inserts (in aluminum pistons for automotive applications) and for pump housings and impellers particularly suited for salt water applications, and for butterfly valves.

Ni-hard irons (nickel-chromium white cast irons with 2.5-4.75% Ni and 0.6-3.5% Cr) offer outstanding abrasion resistance and are used where the shock loading is low. The prime applications are for liners and balls used in the mining and cement industry grinding mills and rolls for steel mills and in paper-making equipment.

Within the gray iron market, the trend is for the nickel gray iron and the Ni-hard materials to maintain their percentages of the market, with the Ni-resist irons increasing their percentage each year.

<u>Ductile iron castings.</u> Nickel usage is 3.4 million pounds per year; the largest applications are in agricultural and metal working equipment — 1.3 million pounds per year. These castings are used in essentially the same applications as are gray iron castings. However, with the use of nickel, plus treatment with magnesium to achieve spheroidal graphite, several important benefits, namely higher yield and tensile strengths and improved ductility, are gained. An additional benefit of nickel is the ability of cams, gears, etc. to be flame and induction hardened in order to provide wear resistance.

Ductile Ni-resist irons (20-25%) have the same basic applications as do the Ni-resist irons, with the benefit of improved ductility. One of the largest applications for this improved alloy is in turbo charger housings for diesel engines used in trucks, off-highway vehicles, railroad service and marine applications.

Trends within the ductile iron category are as follows: ductile Ni-resistant irons have a steep growth curve. As they provide a much improved product over the normal Ni-resist irons, there is a tendency for growth at the expense of the basic Ni-resist irons. The future for ductile nickel gray irons is considered good.

Cast brasses and bronzes. These alloys, which an estimated usage of 7 million pounds of nickel per year have primary applications in marine transportation and process industry equipment, each accounting for approximately 1.5 million pounds per year. Uses for this material include marine propellers and fluid handling equipment as utilized on nuclear submarines The nickel-aluminum-bronze alloys with 5% nickel provide both higher tensile and yield strength than do the materials without the addition of nickel and provides excellent cavitation resistance in marine propellers. The 70-copper, 30-nickel alloys and the 90-copper, 10-nickel are used largely for marine fluid handling and accounts for a substantial number of pounds each year. Additional applications include pumps and valves. The nickel used in this category is largely scrap and remelt material.

General comments. While foundries recycle their own (home) scrap, there is little recycling of scrap once it has been shipped from the foundry; the exception to this is heat resistant castings used in heat treating furnace muffles and fixtures. Normally used scrap castings end up at steel mills where they become part of a basic melt charge. Some foundries, in the past, apparently tried using scrap high nickel aircraft parts such as blades and vanes; however, the aluminum and titanium contained in these alloys makes this material undesirable. Foundries often use scrap bars or billets of stainless steel for remelt purposes; and while stainless chips and turnings have not been used to any degree in the past, recent processing developments which provide improved quality (better degreasing and compacting) may make them an important factor in the future.

A general comment on the ductile iron casting market is perhaps in order. The growth in the use of nickel in ductile iron is markedly steep. Nickel

is not essential to the production of ductile iron but is used as a carrier for the required magnesium addition and also to provide improved properties.

The percentage of nickel used in some alloys tends to be very critical. Some foundries have attempted to stretch their available nickel supply by lowering the nickel content only to find that, by reducing the nickel content slightly, the properties dropped markedly. With regard to substitutions in the sand cast categories above, there is very little choice of other materials. Certainly were there to be an all out conflict, substitutions would be made; however, the parts produced would offer shorter service life, decreased strength or higher unit cost.

The Alloy Casting Institute figures for nickel usage in sand castings indicate that currently 25.3 million pounds per year are being used. This breaks down into two categories — heat resistant, 15.3 million pounds per year; and corrosion resistant, 10 million pounds per year. The difference between these figures and those presented earlier we believe is, in part, explained by the difficulties in obtaining accurate figures due to the rapid growth in the number of parts being produced utilizing nickel (new applications) and increased use of alloys with a higher nickel content.

The Institute's figures show that the current heat resistant alloys average 22% nickel and are used in the following applications:

50%	Heat Treating Furnaces
12%	Petro Chemical
10%	Power Plants
10%	Aeronautical
18%	Miscellaneous Applications

The corrosion resistant alloys average 10-11% nickel with a trend toward 11-12% and are utilized as follows:

40%	Chemical Industry
10%	Oil Refineries

The balance is in miscellaneous applications.

Precision Castings

The precision investment casting industry, which includes parts produced with ceramic shells, uses approximately 5 million pounds of nickel per year. 90% of investment castings go into the production of quality parts; this, in turn, is divided between aircraft gas turbine blades and vanes (93%), and diesel turbo chargers (7%). Due to increased operating temperatures, the trend is to a greater usage of nickel-based alloys. In addition to the blades and vanes, high temperature alloys are used in the production of turbine wheels for diesel and gas piston engine turbo chargers. The remaining 10% is for miscellaneous applications of a general nature and would largely be found in parts produced in stainless steel alloys.

As all of the precision foundry scrap material is, in effect, recycled into the system, there is virtually no loss of nickel. The minute amounts that are lost in removing castings from the gating systems and subsequent finishing is negligible in the overall total.

With regard to substitutions for nickel, it is felt that, were any to be made in gas turbine applications, this would be offset by the increased use of chromium and cobalt. Further, we believe that it is not likely that any across-the-board substitutions could be made without extensive and perhaps impossible engine redesigns.

IV. USAGE IN SELECTED APPLICATIONS

A. Electroplating and Chemicals

Electroplating (Anodes and Chemicals)

Any evaluation of the nickel supply picture, present and projected, is affected by the present shortage which has made itself felt to the user by the voluntary allocation through nickel distributors for the electroplating industry. 1966 consumption was 65,203,000 pounds and the 1967 preliminary figure indicates 56,955,000 pounds in spite of a projected normal growth rate of about 6% per year. The drop of 8 1/4 million pounds reflects the reduced allocated quantities to the electroplating industry. (These figures do not correspond to Bureau of Mines figures, because since 1962 there has been a significant trend toward the use of electrolytic nickel in titanium baskets as anode material. The electrolytic nickel was classified as primary nickel by the Bureau of Mines rather than as anode material for use in electroplating.)

In normal times, about 16% of the total nickel consumed in the U. S. A. is used for electroplating, with the distribution indicating about 50% for automotive use, 25% for consumer products such as appliances (large and small), furniture, utensils, etc., and the remaining for unclassified applications including functional uses of comparatively minor significance in the overall picture. The present nickel shortage has affected large users, such as the automotive industry less than it has small platers of consumer products. Therefore, the distribution mentioned is distorted during the period of shortage.

The automotive use of about 37 million pounds last year is largely for decorative applications although corrosion protection and wear and impact resistance play an important part in bumpers, door handles and windshield wiper parts. The nickel may be electrodeposited directly on steel or on a copper undercoat and is chromium plated for such applications, not only to maintain a clear, bright, appearance but also to contribute to corrosion protection. Thicknesses of nickel

for external automotive and other severe conditions are mostly specified as .0015 inch minimum to withstand the severe conditions of salted streets and industrial big city atmospheres.

There is a trend to increased use of nickel on bumpers because of designs incorporating grille surrounds into the bumper. There is, however, a corresponding reduction in other decorative trim such as grilles, body mouldings, headlamp and tail-light bezels, and interior applications including the dash components. Stainless steel, aluminum and plastics have replaced nickel in many applications over the years.

The unavailability of nickel will continue to plague the industry for several years although the demand is expected to remain steady. More autos will be produced (approaching 10 million units) but the amount of nickel consumed per unit is expected to be reduced.

Within the next five years we can expect an increase in the use of plastics, both plated and non-plated for decorative automobile parts, but the most drastic change is expected to come within a few years by more widespread use of an elastomer coated steel bumper such as the "Endura" bumper featured on Pontiac G.T.O. models this year and expected to expand to other models next year. Other automotive models are expected to follow this trend because of the appeal as a styling innovation. Initial fabrication problems, including long curing times at high temperatures (i.e., 40 min. at 300°F) are expected to be overcome. The main appeal is on models where production is less than 250,000 units per year because of the comparatively low capital investment in equipment.

New chromium plating systems, involving microcracked or microporous coatings have shown themselves to increase corrosion protection and indicate that a reduction in nickel thickness is permissible without loss of corrosion protection. Since a reduction of one-third of the nickel thickness is considered feasible this would mean a savings of about 8 million pounds of nickel on bumpers alone (12 million pounds on entire automobile) by use of such chromium systems.

In a national emergency practically all automotive decorative plated trim could be eliminated; however, such applications as bumpers, door handles and windshield wiper parts would need nickel to provide a durable protective coating under the severe exposure and abrasive conditions.

The second largest area using electroplated nickel with but few exceptions could be drastically reduced in an emergency. Substitute materials such as aluminum, glass, stainless steels and plastics, as well as painted steel could largely replace the decorative plated steel and zinc used in appliances, furniture and utensils. Exceptions would be where heat or abrasion resistance would preclude the use of such substitutes.

This category uses about 15 million pounds nickel per year and although it showed a growth rate of about 8% per year over the past 8 years, changes to stainless steel and colored plastics have changed the market to indicate a reduced growth rate based mainly on population growth.

Further savings in consumption of nickel in electroplating can come from sound conservation measures involving redesign in parts to permit a more uniform distribution of nickel, use of auxiliary anodes and shields and suitable solution reclaim measures.

Electroforming is a small market (about 1 million lb annually) and is expected to show little growth.

Catalysts

At the present time, about 5 million pounds nickel per year are used as catalyst materials. This does not include consumption of an additional quantity involving 3 million pounds of nickel as reprocessed catalytic materials. The catalysts are used in essential industries producing hydrogenated vegetable oils (shortening), hydrogen production and general hydrotreating processes in the refining industry, fertilizers (ammonia), petrochemicals, synthetic fibers and plastisols.

The growth rate over the past ten years has been 5% per year, but without the shortage of nickel the growth rate of the catalyst market could reach 8 or 9% within the next five years. This is indicated by the population growth and the resultant increase in consumption of hydrogenated oils plus new uses in the manufacturing of chemical intermediates.

Catalytically possible substitutes can come from such metals as platinum, palladium, cobalt and copper, however, all of these are costly and would not be available in sufficent quantities to replace this important use of nickel. Additionally copper which could be substituted for nickel in the food industry would involve technical problems regarding its removal since it is poisonous. Its use would increase costs by 3 to 4 times.

Considering the essential industries served by catalysts involving a comparatively small amount of nickel, it is not deemed advisable to consider substitutes.

Chemicals

The nickel figures concerning electroplating applications include that used in plating chemicals. The remainder of nickel chemicals involve less than 500,000 pounds per year and usage is declining.

These chemicals are used in the manufacture of alkaline batteries, for treatment of wheat rust and in ceramic applications. There is no area involving a significant upward trend. Another declining use is in the ceramic industry where one-coat porcelain enamels are gaining and do not require nickel for coating bonding to the steel.

B. Nickel Usage in Aerospace, Hydrospace, and Industrial Gas Turbines

General Background

The role of nickel in both aerospace and hydrospace applications varies in that it serves in some cases as the base metal (on the order of 70% in nickel base superalloys), and in others as a relatively minor alloying constituent (as low as 2-1/2% in certain steels). Nickel has properties which fulfill the necessary requirements for many applications in both the aerospace and hydrospace fields. Briefly, it is the ideal base metal for superalloys which must maintain certain of their room temperature properties at high temperature, because of its relatively high melting point (2650°F), good corrosion resistance, and ability to take into solution a number of metallic elements which can strengthen it. Nickel also forms the gamma prime intermetallic phase with aluminum and titanium. The gamma prime phase can take very large amounts of other elements into solution. This ability can change its properties such as hardness and stability, and makes it the most potent strengthener in nickel base superalloys. As an alloying constituent in stainless steels, nickel serves to promote and retain an austenitic structure at all temperatures and contribute to corrosion resistance. When alloyed with copper, outstanding corrosion resistance (atmospheric and sea water) is obtained.

Aerospace Applications

Gas turbine engines — specific uses and potential substitutions. The major use of nickel in the aerospace field has been and will continue to be in air-breathing gas turbine engines primarily in the form of nickel base superalloys for turbine components (disks, buckets, stator vanes, combustors), and the disks, blades, and vanes of the later compressor stages. A considerable quantity is also used in highly alloyed iron base alloys such as A-286 for shafting, bearing housings and duct work. Since the key to improved engine performance is operation at higher cycle temperatures, the immediate outlook is that more engine components will have to be made from high temperature nickel base alloys (i.e., more of the compressor stages, since the later stages for advanced engines will be

subjected to higher air temperatures). Much of the possible conversion has already taken place in some engines.

Turbine inlet gas temperatures on the order of 1900 to 2300°F are used in experimental engines and potential substitutes for nickel base superalloys in the hot turbine components would have to be either cobalt base alloys, chromium alloys, columbium or tantalum alloys for the highest temperatures, or composite materials. In the latter case, fibers of a higher melting point material such as tungsten can be enclosed in a lower melting point metal or alloy matrix (probably nickel or cobalt base). however, the total nickel requirements would not thereby be reduced. It is doubtful if problems of incompatibility between fibers and matrix will be overcome in the immediate future to permit these materials to become a significant quantitative substitute. At present cobalt base alloys, due to the lack of a potent strengthening mechanism such as the gamma prime phase, have lower strength than nickel base alloys over most of their useful temperature range. A one-for-one substitution could therefore not be made, although for lower stress applications (i.e., combustors, stator vanes) cobalt base alloys might be, and often are, used in place of nickel base alloys. Problems associated with inherent low-temperature brittleness and severe nitrogen embrittlement upon exposure to high temperature air make it unlikely that chromium base alloys will prove to be a major substitute for nickel base alloys in the next five years. Finally, the inherently poor oxidation resistance of the other refractory metals (columbium, tantalum, molybdenum and tungsten) is a serious deterrent to their potential use for these applications.

Superalloy Requirements

The SST engine (GE-4) will require approximately 40,000 pounds of superalloy mill product per engine plus 18,000 pounds of titanium. It is designed to produce 63,000 pounds of thrust at a finished weight of 11,500 pounds. Typical of most aircraft gas turbines, the input raw material weight is 6-10 times the finished weight. The high scrap generation of costly materials is a constant incentive to develop more efficient fabrication methods and to utilize more scrap in the production of superalloys.

The trend in the alloys used is toward higher purity, more casting alloys in the hottest parts, and nickel-base alloys replacing stainless steels and iron-base alloys such as AM-350, AM-355, and A-286.

The following alloys are currently popular with aircraft engine manufacturers:

Ni-Base Alloys	Nominal Ni, wt. %
Inconel 713C	75
Inconel X (Inconel X-750)	74
Waspaloy	58
M-252	57.5
Astroloy	57
René 41	55.5
Inconel 718	55
Udimet 500	55
Udimet 700	54
Hastelloy Alloy X	49
Incoloy 901	42.5
Austenitic Alloys	
V-57	25.5
A-286	25
Cobalt-Base Alloys	
X-40 (HS-31)	11
L-605 (HS-25)	10

Air frames — specific uses and potential substitutions. The other major area of use for nickel in the aerospace field is in air frame structures. This is mostly in the form of stainless steels and nickel base alloys for hot air ducting, notably thrust reversers; nickel base superalloys for hot structural components around engine mounts; and alloy steels for landing gears. Future manned

intercepters may require nickel-base alloys for airframe structures, as exemplified by the X-15 and B-70, supersonic vehicles, will certainly require nickel alloys. Substantial usage is unlikely, however, before 1975.

The picture insofar as substitute materials is concerned is not bright. Since higher temperatures are envisioned with future aircraft, the stainless steels and iron-base alloys can only be replaced by materials of higher temperature capability which will probably be nickel-base superalloys. Thus the trend of usage is in the direction of greater nickel consumption of air frames. The most likely possibility of a substitute material would be cobalt-base superalloys.

Estimated Use Levels

Aircraft gas turbine engines. Estimates of the quantities of nickel used in aircraft gas turbine engines were obtained from all of the major engine manufacturers. Unfortunately, the response to specific requests as to a breakdown of the nickel used in superalloys and in stainless steels in engines, finished weight vs. mill product weight, and a further breakdown on the basis of engine class (i.e., power output) varied as to completeness. It is thus impossible to provide as clear and complete a picture as might be desired. Furthermore, some of the manufacturers placed restrictions on the use of some of the information provided. For example, one provided nickel usage data in terms of the number of engines produced, but did not wish the latter figures to be quoted. Others requested that restraint be used in identifying the numbers given with the company name. The following tabulations, therefore, do not identify the company source and attempt to provide as close to a common breakdown of the usage levels as the information provided permits.

Finally, the definitions of raw material and mill product weight varied for the different manufacturers. Thus, at one extreme, the mill product was defined as the weight of rough forging stock and castings bought from the supplier. At the other extreme, it was defined as the raw billet or bar stock before forging and raw casting after removal of gates and risers. The best estimate, as

determined from discussions with manufacturers, of the amount of chips generated in square cutting a piece of material, for say a wheel forging, is about 15% of the total weight. Since this is a relatively low figure and applies only to some of the data presented, no attempt was made to account for such material losses in compiling total usage.

Table 12 presents a breakdown of nickel usage by engine category. According to the first manufacturer, the finish weight of nickel per engine ranges from 300 to 1,700 pounds for power output levels of 8,000 to 40,000 pounds of thrust. Similar figures are given for nickel superalloy finish weights for comparable power outputs by a second manufacturer. He shows finish weights of nickel superalloy parts ranging from 575 pounds to 2,669 pounds for engines with thrust outputs of 10,000 and 42,000 pounds. The utilization ratio of nickel in engines, when given in terms of finished contained nickel weight divided by contained nickel mill product weight ranges between 22.1 and 40% according to the data from manufacturer number 1. The utilization ratio of finished nickel alloy parts weight to nickel alloy raw material weight according to manufacturer 2 ranges from 16.4 to 33.6%.

Table 13 lists the total nickel usage. Here, the figures are presented in terms of contained nickel usage for various time intervals. Assuming parity between 1969 and 1968 usage levels (manufacturer 1 gives 1969 figures and manufacturer 2 gives 1968 figures). The total current yearly mill product usage of contained nickel in gas turbine engines is 17,498,239 pounds. Estimates of the amount to be used five years from now were not given by all of the manufacturers. Where they were made, approximately a 30% higher requirement was envisioned. The actual total nickel usage figure for engines would exceed the figure given if every single small manufacturer were included. The amount of this increase, based on conservative estimates, might be another 1,000,000 pounds. If an attempt were made to account for raw material in the form of casting risers and trim from forgings, the total might go up another million or so pounds.

Table 12. Breakdown of Current Yearly Nickel Usage by Engine Category

Manufacturer	Engine Power Output	Total Engine Wt. Lbs/Engine	Contained Ni Finish Wt. Lbs/Engine	Contained Ni[a] Mill Product Wt. Lbs/Engine	Ni[c] Alloy Raw Mat'l Wt. Lbs/Engine	Finished Wt. of Ni Alloy Parts Lbs/Engine	Utilization Ratio: Finished Ni Alloy Parts Wt. / Ni Alloy Raw Material Wt. %	Utilization Ratio: Finished Pure Ni Wt. / Contained[a] Ni Mill Product Wt. %	Finished Ni Alloy per Engine %
1	1500-3000 Shaft HP	400-800	30-80	100-200				30-40	
	4000 Lb Thrust	500	40	120				33	
	8000 Lb Thrust	1000	300	1000				30	
	16,000 Lb Thrust	3600	600	1600				37.5	
	40,000 Lb Thrust	7000	1700	7700				22.1	
	60,000 Lb Thrust	11,000	2800	11,300				24.8	
2	10,000 Lb Thrust	2118			2176	575	26.4		27.2
	15,000 Lb Thrust	3196			2535	637	25.0		19.9
	18,000 Lb Thrust	4260			3987	1340	33.6		31.4
	20,000 Lb Thrust	4060			9578	1628	17.0		40.1
	42,000 Lb Thrust	8330			16,300	2669	16.4		32.1
3	1000-3500 Shaft HP							50.7	
	1500-5000[b] Shaft HP							50.0[b]	

[a] Mill Product Weight defined as weight of rough forging stock and rough castings bought from supplier.
[b] Estimated 1973 figure.
[c] Raw Material Weight defined as weight of sheet, bar, billet, and castings.

Table 13. Projected Nickel Usage

Manu-facturer	Engine Category	Contained Ni[c] Total Mill Product Wt. Lbs.		Contained Ni[a] Total Mill Product Wt. Lbs.		Contained Ni[b] Total Raw Material - Wt. Lbs.						Ni Alloy[b] Total Raw Material - Wt. Lbs.					
		1968	1973	1969	1974	1st 1968	2nd 1968	3rd 1968	4th 1968	1st 1969	2nd 1969	1st 1968	2nd 1968	3rd 1968	4th 1968	1st 1969	2nd 1969
1	Small Turbo Shaft & Turboprop up to 4000 HP			22,132	55,2[illegible]3												
	Small Turbofans & Turbojets up to 10,000 lb Thrust			174,990	169,134												
	Medium Turbobofans & Turbojets 10,000–20,000 lbs Thrust			1,078,395	–												
	Large Turbofans & Turbojets > 20,000 lb Thrust			1,481,600	4,555,450												
2	All Categories					3,199,129	3,163,389	3,720,307	3,747,297	3,601,[illegible]66	4,014,312	6,842,172	7,261,727	7,172,009	7,947,124	8,386,600	9,704,453
3	All Categories	446,000	650,000														
4	320–340 Shaft HP	120,000	30 to 35% higher														
	3500–4500 Shaft HP	290,000															
	14,000–15,000 lbs Thrust	168,000															

[a] Mill product weight defined as weight of rough forging stock and castings bought from suppliers.
[b] Raw material defined as sheet, bar, billet, and castings.
[c] Mill product weight defined here as raw billet or bar before forging and raw castings after removal of gates and risers.

Industrial Gas Turbines

These turbines are used as peaking, base load, and auxiliary generators in the electric utility industry. In the industrial sector they serve as a basic power source supplying shaft power, electrical energy, and heat. The split in applications is about 60/40 between electrical utilities and industrial installations. The significance of this market is the recent rapid growth of sales primarily to the domestic electrical utilities. In 1966 orders placed were about four times the rate of those of a few years previously. Future requirements indicate a continuing market for 2-1/2 to 4,000,000 H.P. of capacity per year. The following are shipments of industrial gas turbines obtained from a major manufacturer:

	H. P. in thousands	
Year	For Domestic Use	Total World Use
1960	150	500
1961	220	710
1962	450	1,053
1963	460	1,580
1964	700	3,000
1965	687	2,300
1966	1,144	2,900
1967	3,360	5,000
1968	5,490	7,500

The above data covers turbines rated from 300 to 50,000 H.P. in non-aircraft applications. An average of .15 to .20 lb/HP for the nickel content of the present mix of gas turbine units is a reasonable assumption. Recent yearly consumption of nickel by all stationary gas turbine producers might be estimated as in the neighborhood of 5 million pounds.

Air Frames. The primary use of nickel in air frame construction has been described above. Table 14 summarizes the usage for one major commercial air frame manufacturer. The figures given are in terms of raw material ordered for the last three quarters of 1968 and the first two quarters of 1969 by the

TABLE 14. CURRENT NICKEL USAGE IN AIR FRAMES
As provided by one major aircraft manufacturer.

Material	2nd 1968 Quarter	3rd 1968 Quarter	4th 1968 Quarter	1st 1969 Quarter	2nd 1969 Quarter
Stainless Steel (Primarily 302 & 321)	1,300,000 lb	1,800,000 lb	1,300,000 lb	1,300,000 lb	1,200,000 lb
Nickel Content of Stainless Steels	117,000 lb	162,000 lb	117,000 lb	117,000 lb	108,000 lb
Nickel Superalloys	21,000 lb	28,000 lb	13,000 lb	12,000 lb	11,000 lb
Nickel Content of Superalloys (Assumes 65% Ni)	13,600 lb	18,200 lb	8,500 lb	7,800 lb	7,200 lb

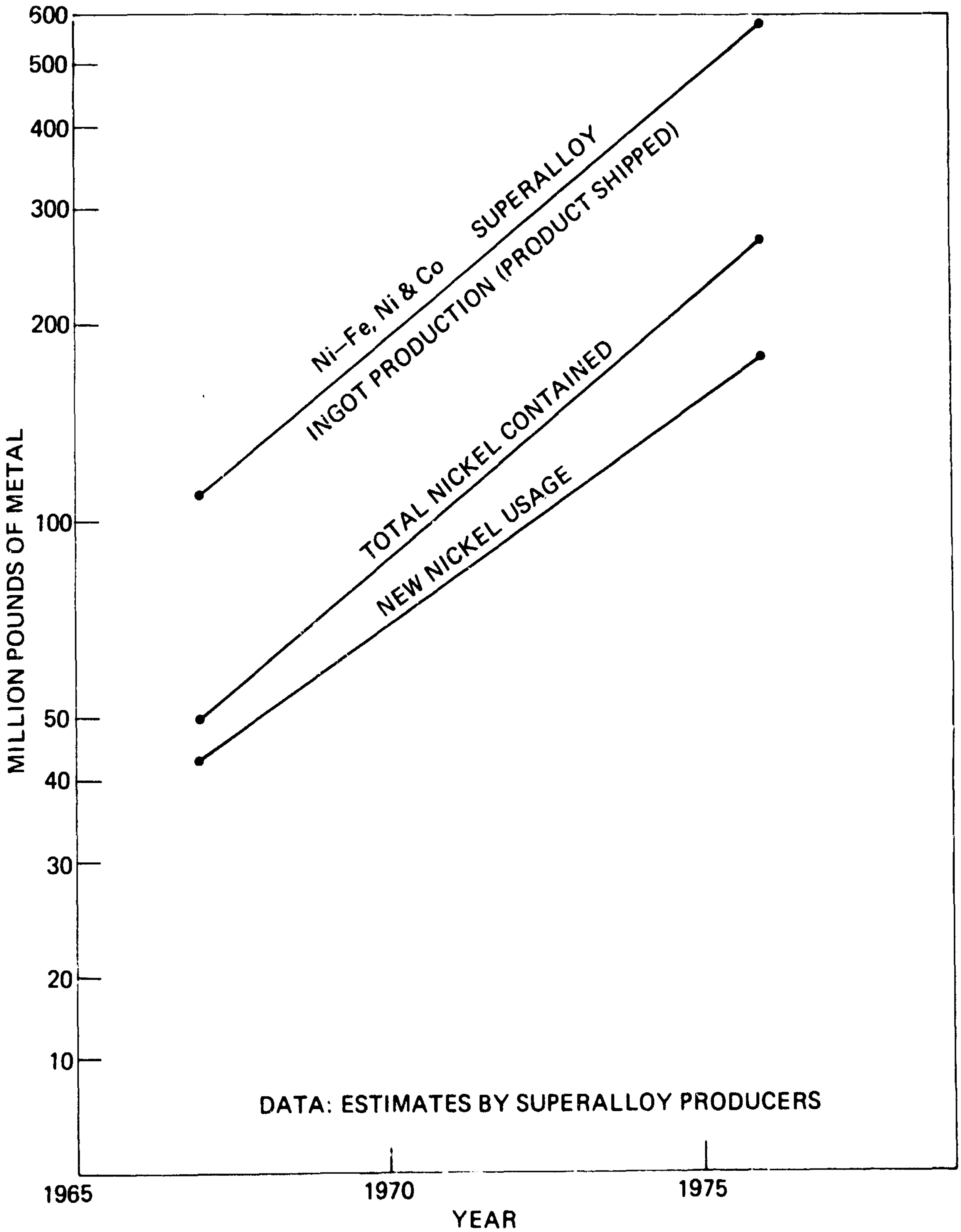
manufacturer for his own use. If an average nickel content of 9% is assumed for the two stainless steels and an average of 65% nickel content assumed for the nickel superalloys, the actual nickel usage can be calculated. Those latter numbers are also listed on the Table. The total nickel usage for the last three quarters of 1968 and the first quarter of 1969 for this manufacturer would then be 561,100 pounds. If the usage total shown in Table 14 is multiplied by 5, which assumes that each major air frame manufacturer (commercial and military) uses the same amount of nickel, the total amount is relatively small (approximately 2,800,000 pounds).

Unfortunately, this type of tabulation provides only a small part of the picture. Much of the work of the air frame manufacturers is subcontracted. No fixed figure can be determined as to the amount of subcontracting that is done. This varies from one model of airplane to another. In one case, it may be 30%, in another 60%. Some of the major types of work that are subcontracted are manufacture of engine mounts and landing gears, and portions of the air frame such as wings, etc. Any number of subcontractors may be involved so that it becomes next to impossible to track down the nickel used by each subcontractor to a particular air frame manufacturer. In the light of the figures made available by the producers, that 3,307,881 pounds of nickel went into alloy steels and 13,787,500 pounds of nickel into stainless steel for the aircraft industry, it appears that much more substantial quantities of nickel are used in air frame construction than an estimate based on Table 14 would indicate. Of course, the figures include engine usage as well, but they are still at least 3 to 4 times greater than the 2,800,000 pound figure shown above. One estimate of consumption trends for superalloys for all applications is shown in Figure 3.

Hydrospace Applications

Specific uses and potential substitutions. Nickel is used in the hydrospace field in a wide variety of applications. Gas turbines constitute a large and growing market for nickel. However, unlike the aerospace field, where the nickel base alloys (about 70% nickel) are the major use factor, the greater portion of the

FIGURE 3. Trends in Consumption of Nickel in Superalloys.



nickel used is as an alloying constituent in various other metal bases. These include the copper-nickel alloys (90% Cu - 10%Ni, 70% Cu - 30% Ni) used extensively for condenser tubing and the nickel-aluminum bronze alloys (approximately 4% nickel) for pump casings and valves. The latter alloys are also employed in propellers and other applications that see direct sea water. Stainless steel usage is another major factor. This is employed for deck plates, trim, handrails, high pressure steam lines, as well as for tubing. Another important use of stainless steel is in commercial tankers and barges for liquid containment. Its use in hull structures is nominal. Low alloy steels of the HY-80 type (2-1/2% nickel) are also heavily used for hull materials on submersible vehicles. Such steels also see service in the hull structure of capital ships such as carriers. High nickel content alloys, such as Monel, are also employed for high temperature shafting, fasteners, and torpedo tubes. The trend in steel shafting might be toward high nickel steels in shafts to secure better fracture toughness.

The situation regarding alternate materials is such as to generally involve alloys with higher nickel content. Thus, the next generation of hull materials for submersible vehicles will probably be the HY-130 or HY-150 steels which contain 4-1/2 to 5% nickel, about twice the nickel content of those currently being used. The use of 18% nickel maraging steels is not likely to become a significant factor for years to come in submersible vehicles, but in any case this would not alleviate the nickel problem. With respect to the copper-nickel alloys, the trend in research is to develop higher strength Cu-Ni alloys which probably involve higher nickel content. There is some possibility of substituting titanium alloys for the copper-nickel alloys. Research looks encouraging in that some titanium alloys have better corrosion resistance and better strength-to-weight ratios. However, economic factors must warrant making the changeover. It is presently estimated that over the next five year period the substitution of titanium for copper-nickel alloys will be on the order of less than 10%.

Estimated Use Levels

It has been possible to obtain some unclassified information from the producers. The figures are listed in Table 15. The alloy steel designation includes primarily the low nickel content steels used for hull materials. The total nickel content of the cast brasses and bronzes is included in the 5,200,000 pound figure given for the cupronickel alloys in the tabulation. Total nickel usage for all applications is 13,879,420 pounds. The last column indicates the percentage of nickel used in the various material categories. Their application has already been described in detail in a previous section. The cupronickel alloys account for the greatest use factor (37.5%) and the high nickel alloys (31.7%) are second. It is interesting to note that if the steel usage (both stainless and alloy steels) is totaled, a use factor of 30.8% results. Compared on this basis nickel is approximately used in equal quantities in steels, high nickel alloys and cupronickel alloys in hydrospace applications.

TABLE 15. NICKEL USAGE IN HYDROSPACE APPLICATIONS

Material	Nickel Content, Lb	% of Total Nickel Usage
Cupronickel[a] Alloys	5,200,000[a]	37.5
High Nickel Alloys	4,400,00	31.7
Cast Brasses and Bronzes	2,870,000	
Stainless Steel	2,000,000	14.4
Alloy Steel	2,279,420	16.4
Total:	13,879,420	

[a] Figure includes cast brasses and bronzes.

C. Nickel in Automotive Applications

Current usage of nickel by the automotive industry is estimated to vary from 4.5 pounds average for passenger cars to over 5.0 pounds average for trucks, with a total of 52,500,000 pounds reported for 1966. Trends indicate a probable decrease in requirements for some applications and an increase for others during the five year period covered by this study. The combined effect of all factors during this interval is expected to be a slight decrease in nickel usage, but within the limits of 4.5 to 5.0 pounds per average vehicle. Total industry requirements for nickel will be affected more by production volume than by technical changes. The lead time for major changes is normally over five years.

Present Applications and Technical Requirements

Electroplating. About 25,000,000 pounds per year is used on bumpers; 12,000,000 pounds per year on other decorative parts (primarily zinc die castings). Increasing durability requirements and increasing corrosion exposure impose a continuing technical challenge to upgrade performance and maintain minimum nickel usage.

Stainless steel (wrought). Stainless steel is widely used for wheel covers, with about 6 pounds (mostly Type 301) on 85% of current cars. Substantial amounts of Type 434 are used for trim strips and moldings. Wrought stainless is used for many engine valves with nickel content varying over a wide range for passenger car and truck gasoline engines and truck diesel engines. If high temperatures will be needed in devices to provide emission control, highly alloyed materials may then be required. However, it cannot now be said that nickel will be needed in the alloy. A firm emission target is the first requirement. After that, the alloy requirements will depend on the approach to obtain emission control actually used (combustion chamber redesign, exhaust manifold construction, use of afterburner, etc.). Heat tubes on emission control devices are usually Type 309, or 35 Cr - 20 Ni. Some mufflers and exhaust pipes for heavy duty equipment use nickel bearing stainless. Many exterior tapping screws are made

from Type 305 stainless. Total annual usage of wrought stainless is estimated equivalent to 7,100,000 pounds of nickel. For these various applications, strength, corrosion resistance, elevated temperature properties, and formability are factors in material selection.

Heat resistant castings. Many valves are produced by casting; typical nickel content is 14%, with some special engines requiring much higher amounts. Heavy duty engines frequently use nickel-bearing valve seat inserts. Some exhaust manifolds use nickel alloy castings, along with turbocharger housings for some diesels. Alloys such as 713C are used for turbocharger wheels. Each high temperature application requires a careful balance of strength and other properties. Total automotive requirements for nickel in heat resistant castings is estimated at 1,200,000 pounds per year.

Alloy steel. About 2,400,000 pounds of nickel per year is used as an alloying element in automotive steels, mostly in gears and other heat treated highly stressed parts. Nickel content is usually higher for heavier section truck components. Hardenability, wear resistance, impact resistance, and consistent response to production processes govern selection for individual applications.

Grey and ductile iron castings. Nickel usage in these automotive applications is estimated at 2,150,000 pounds per year. Applications include many camshafts, some truck engine blocks, some heavy duty brake drums, and as a carrier for magnesium in some ductile iron processes.

Electrical resistance alloys. Automotive sparkplug electrodes require about 870,000 pounds of nickel per year, in the form of special alloys containing from 75% to over 90% of nickel.

Cupronickel. Some transmission oil coolers are made from cupronickel, as best suited to the production process employed. Nickel usage is estimated at 1,250,000 pounds per year.

Miscellaneous. Other automotive uses of relatively small amounts of nickel include alloy steel castings (66,000 pounds of nickel), brass and bronze castings (18,000 pounds), permanent magnets (24,000 pounds), in bi-metallic springs, and as an ingredient in some sintered metal parts. In each instance nickel is used because of the particular characteristics necessary for satisfactory performance.

Trends and Future Requirements

Over the five year period covered by this study, it is anticipated that there will be some decrease in the amount of nickel required for automotive decorative applications (electroplating and stainless), and some increase where functional performance of components is the primary consideration. The magnitude and timing of changes in nickel required for individual applications cannot be predicted with confidence.

A decrease of about 1,000,000 pounds of nickel per year was attributed to drastic reduction in 1968 in bright interior automotive trim to meet reflection requirements, and an additional reduction of similar amount is estimated for 1969 because of a trend to less exterior bright trim. Some new designs of bumpers and grilles use more painted steel or plastics, and have less plated area. Variations in styling from model to model over a five year period cannot be predicted with confidence, but it appears that nickel requirements may decrease somewhat for bumpers and grilles. On the other hand, a trend to more plated plastics replacing zinc die castings might increase nickel requirements compared to present practice for comparable parts.

Nickel used for present functional automotive applications is expected to increase. Steadily increasing pressures for even better reliability and durability, increasing operating stress levels, and increasing engine exhaust emission control requirements, all indicate trends in performance requirements where increased nickel content is a probable approach.

Gas turbines may be an important factor in future automotive industry nickel usage, with up to 60 pounds of nickel required per unit. During the period covered by this study, however, their impact should not be significant. Initial production is not expected until after the present nickel shortage has been relieved by increased supplies, and quantities produced during the latter portion of this five year period should represent only a fraction of one percent of industry nickel usage. If after five years from now gas turbines (probably for trucks) are built at the rate of 10,000/year, this number of engines would represent only about 1/10 of 1% of the total quantity of engines now made. Acceleration in timing or quantities planned might indicate a need for reassessment.

Potential Substitutes for Nickel

The need for considering alternates for nickel will depend (in the absence of an emergency) more on appearance factors and production volume of vehicles than on technical considerations of specific applications. Trends for more painted and less plated exterior area have been noted. Plating systems using more copper and less nickel are in use in some instances. A continuing trend to replace stainless trim with aluminum is evident.

For functional uses, alternate compositions usually involve drastically modified processes, with cost and performance risks that must be assessed in each instance. A plan for investigating alternates would involve extensive engineering and manufacturing studies and tests (based on assumptions that may not be valid) of relative availability of different metals. In general, where nickel used is contained in raw materials purchased (stainless steels, alloy steels, etc.), the suppliers of such materials would be expected to evaluate alternatives and advise practical approaches. Where nickel is used as an ingredient in castings it is normally contained in scrap, and supply of either nickel or alternatives would depend on trends of scrap availability. Under these conditions, it is difficult to project a realistic program to evaluate substitution potentials.

D. Nickel in Coinage

Although nickel-containing alloys have been used in coinage since ancient times, and Canada has used a pure nickel five-cent piece since 1922, a clear-cut trend toward major use of nickel in the coinage of the world waited until the mid-1940's to develop. India introduced pure nickel coins into its coinage system in 1945, while Great Britain began to mint 75 copper-25 nickel cupronickel alloy coins in 1946.[1] Since then, many other countries of the Free World have adopted nickel and nickel-containing alloys, or substantially increased their use of these materials. 1965 saw a dramatic jump in the consumption of nickel for coinage when the United States introduced a sandwich coin composed of 75-25 cupronickel cladding on a copper core for dimes and quarter dollars.[2,3]

An important reason for the increased usage of nickel in coinage is that nickel and nickel-containing alloys are preferred replacements for silver. The latter is rapidly being phased out of coinage throughout the world because it is becoming increasingly scarce, because the rising price of the metal makes it unsuitable as a coinage material, and because there are a number of growing industrial and defense applications to which the metal is uniquely suited. The pure nickel coinage adopted by India replaced that country's silver rupee, half rupee and quarter rupee. Great Britain's introduction of cupronickel was designed to facilitate repayment of the silver she had borrowed from the United States during World War II. Again, the United States sandwich material is a replacement for coin silver.

Another reason for the increased consumption of nickel in coinage is that pure nickel and 75-25 cupronickel are tending to replace coinage materials other than silver. The basis for this kind of shift is founded partly in the properties of the materials and partly in psychology and tradition. Nickel and cupronickel have the required corrosion and wear resistance, are readily available in the needed quantities and forms, can be put through coin manufacturing operations satisfactorily, but in addition have a pleasing "feel" and "heft," and are metallic gray

in color. Again, nickel is sufficiently low in cost that the problem of "intrinsic value" should not arise, as it has in the case of silver.

The significance of the color, in particular of nickel and cupronickel, resides in the definite preference of nations toward a metallic gray or "silvery" appearing metal for the coins of higher denomination. Thus, pure nickel and cupronickel tend to gravitate toward such coinage. On the other hand, there seem to be no strong color preferences for the minor coins of the world. Here, brasses, bronzes, and a number of other alloys appear to be equally satisfactory from the color standpoint.

A third reason for the increased usage of nickel in coinage is simply the steadily increasing number of coins being produced and used throughout the world. Broadly speaking, a country's coinage requirements are influenced primarily by the size of its population and level of its economic activity. A predominant factor influencing coinage demand in economically advanced countries is the number of coin-operated vending machines and other devices in existence.

Figures for the consumption of nickel in coinage are given in Table 16. The surge in the consumption of nickel that took place during 1965 in the United States, as the cupronickel-copper sandwich coins entered the field to replace coin silver dimes and quarter dollars, is quite evident. The data also reflect the continued high rate of production of these coins through 1966 and 1967. However, now that the transition has been successfully effected, a tapering off of production is anticipated at the present time; and it is expected that this will be followed later on by a steady gradual increase in production.

The available data suggest that total Free World consumption of nickel for coinage also took a sharp increase during the period in which the change-over in United States coinage occurred. Of this increase, some 2,100,000 pounds are attributable to the fact that the 1966 data cover 90 countries, while the 1963 data relate to only 71 countries. Another 3,000,000 pounds reflects the surge in the production of cupronickel five-cent pieces and sandwich dimes and quarters in the

TABLE 16. CONSUMPTION OF NICKEL IN COINAGE
(in pounds)

Year	United States	Total Free World	Reference
Calendar 1963	1,256,000	9,040,000	(4)
Fiscal 1964	1,736,000		(4)
Fiscal 1965	4,348,000		(2)
Calendar 1966	4,334,000	17,104,000	(5)
Fiscal 1967	3,748,000		(5)
Fiscal 1968	2,008,000[a]		(6)
Fiscal 1969	1,596,000[a]		(6)
Fiscal 1970	1,810,000[a]		(6)
Fiscal 1971	1,856,000[a]		(6)
Fiscal 1972	2,048,000[a]		(6)
Fiscal 1973	2,218,000[a]		(6)
Fiscal 1974	2,344,000[a]		(6)

[a] Estimated.

United States. The remaining 5,000,000 pound increase is attributable to increases in total coinage production and to switches from other metals to pure nickel or nickel-containing alloys around the world. For example, these factors resulted in a three-fold increase in the consumption of nickel in coinage in Japan between 1963 and 1966.[5]

A further surge in Free World consumption of nickel in coinage can be expected in 1968 as Canada switches over to pure nickel coins for all denominations. To accomplish this, the Royal Canadian Mint will require an additional 2,000,000 pounds of nickel, at a minimum, during 1968. Furthermore, Canadian experience can be expected to parallel that of the United States and, hence, sharply increased coinage production by Canada can be looked for during the succeeding two or three years. Meanwhile, other countries especially in Asia and South America can be expected to increase their usage of nickel in coinage during the coming years. Accordingly, total Free World consumption of nickel in coinage for 1968 is likely to be about 19,000,000 pounds. Moreover, it is probable that annual Free World consumption will move upward from this figure at the rate of 1,000,000 or 2,000,000 pounds per year for the next few years.

In spite of the rapidly increasing interest in pure nickel and in such nickel-containing alloys as 75-25 cupronickel, this metal is no more essential in coinage than any other metal. Various alternatives are available. The selection of the alternatives depends on the specific conditions prevailing in the particular country.

In the United States, the physical property requirements imposed by sophisticated coin-operated devices constitute a dominant limiting factor. Even so, any one of several materials could be substituted directly for the cupronickel used in United States five-cent pieces. The substitute material must be nonmagnetic and possess a density approximately the same as that of the cupronickel. A number of brasses and bronzes are available that should be able to meet these requirements and be satisfactory in other important respects.

A logical alternative to the sandwich material used in the United States for dimes and quarters is gilding metal, an alloy consisting of 95% copper and 5% zinc.[7] This alloy satisfactorily matches both coin silver and cupronickel-copper sandwich metal in those properties that are critical for coin-operated devices. In addition, gilding metal probably can be made available in the required quantities and shapes, and also can negotiate coin production operations very successfully. Of course, coins produced from this alloy would be red in color rather than metallic gray.

Some time in the more distant future (well beyond the period encompassed by this report), it is probable that the economically and technologically advanced countries will make less and less use of coins. A credit card or similar device can be visualized as taking over an increasing number of functions now served by coins.

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E. Nickel in Batteries

Nickel for use in Ni-Cd alkaline cells (powder, contactors and grids) was consumed at the rate of about one million pounds per year in 1967. An increase in consumption of about 10% can be expected in 1968, with a consumption level of two million pounds in 1972 being a reasonable estimate. A limit on the expansion of this market may be set by the availability of cadmium (being a by-product of zinc smelting, production does not respond flexibly to changes in demand for cadmium).

V. CONCLUSION

Nickel is one of very few materials for which, for the last several years, supply has never seemed able to outstrip demand. From consideration of the changing resource picture, nothing that came to the attention of the committee suggested that the present tight supply situation will change appreciably within the next few years, although it appeared that a balance with demand will be achieved in about 1971-1972. This prediction assumes a lessening, or at least not an intensification of the Viet Nam conflict.

On the other hand. the prospects for reducing consumption or substituting another material for nickel, for the most part, looked technically feasible. In some applications, such as high temperature alloys for gas turbines, substitute materials would impair performance. In others, such as alloy steels, the possible substitute elements such as molybdenum, chromium, vanadium, etc., may themselves be in even more limited supply. A major opportunity for conserving nickel, should this become necessary, is in the substitution by manganese of about half the nickel in the 300 series stainless steels. The technology for making this shift is here; an incentive to make the change has been lacking.

Within the next five years, world nickel demand is expected to increase by roughly 8% per year from 820 million pounds of primary nickel in 1968 to 1.3 billion pounds in 1973. Significant growth areas include stainless steels, superalloys in gas turbines for aircraft and stationary power, and cupronickel for desalinization.

Heavy Japanese and European purchases of our nickel-bearing scrap have complicated the problem, which in the past has been alleviated somewhat by stockpile releases. The quality of the material in the Government stockpile is considered adequate for most projected applications.

Substitutes for applications involving nickel are available for many uses, but often only with penalties in cost, fabricability, performance, or service life. Table 17 summarizes specific substitution possibilities.

TABLE 17

SUMMARY OF SUBSTITUTABILITY FOR NICKEL IN VARIOUS APPLICATIONS

Application	Present Material	Possible Substitutes	For details see page
Construction Industry	Chrome-nickel stainless	200 series stainless; carbon steel, masonry	28, 46
Automotive	Nickel plate	Paint, Al, white brass plating, plastics	71, 89
	Heat-resistant castings	Alloy facing & seat inserts for valves on unalloyed metal	90
	Ni-Alloy steel	Ni-free compositions of equivalent hardenability	42, 90
	Ni-Iron castings	Higher Si, Mn, Mo or Cu	65, 90
	Stainless truck bodies	Al, carbon steel	32
Cooking & Food Processing Equipment	Chrome-nickel stainless	Cr-plate, glass, Al, cast iron, enameled iron	32
Industrial Equipment	Stainless condenser tubing	Al-brass, Admiralty metal, Ti	33
Gas Turbines	Ni-base superalloys	Co, Cr, Cb, Ta	70, 75, 78, 82
Ship Hulls	HY-150	HY-80, Ti	37, 44, 86
Propeller Shafts	Monel, Cr-Ni stainless	200 series, alloy steel	37, 86
Electrical Equipment	Maraging steels	400 series stainless	35, 45
Buried Distribution Lines	Nickel-bearing stainless	Lead sheathing	35

TABLE 17 (continued)

SUMMARY OF SUBSTITUTABILITY FOR NICKEL IN VARIOUS APPLICATIONS

Application	Present Material	Possible Substitutes	For details see page
Heavy Construction Equipment	Ni-containing alloy steels	Alternate Cr-Mo steels	46
Railroad Cars	Cr-Ni or Cr-Ni-Mn stainless	Carbon steel, Al	38
Coinage	Nickel	Gilding metal	97
Catalysts	Nickel	Pt, Co, Cu	73
Electrical Alloys (magnetic sealing, resistance)	High-nickel alloys	Fe-Al-Si & Fe-Cr-Al alloys, ferrites, silicon carbide, high purity iron	50

NOTE: It is recognized that the substitutions suggested above will involve any of the following: additional expense, redesign, shorter life or impaired performance, or use of another material which is in short supply.

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13. ABSTRACT

Production and consumption of nickel have nearly doubled in the last ten years. Nickel is used in many important military and civilian applications, incorporated in stainless steel and a wide variety of ferrous and non-ferrous alloys as well as in plating. Since production of the metal has tended to lag behind needs for many years, it seemed desirable to examine the trend in applications and the possibility of substituting more plentiful materials in the event of an emergency.

Stainless steels are the largest consumer of nickel, followed by superalloys, electroplating, and alloy steels. The function of nickel is not unique in practically any application. However, substitution will nearly inevitably result in a performance or an economic penalty. The report points out the substitution possibilities in a broad way. Any specific case, however, requires an engineering assessment which cannot be made in the abstract. The growth rates for the various applications of nickel are estimated.

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